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Influence of Fatty Alcohols and Acids on the Clarity and Biota of Impounded Reservoirs

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INFLUENCE OF FATTY ALCOHOLS AND ACIDS ON THE CLARITY AND BIOTA OF IMPOUNDED RESERVOIRS

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ABSTRACT

Thsi project presents results on a laboratory and field investigation of some of the biological and physical effects as a result of the use of a 1:1 mixture of hexadecanol and octadecanol. Laboratory investigations were concerned with changes in pH, hardness, alkalinity, turbidity, surface clarity, oxygen diffusion, diurnal oxygen, chlorophyll, bacterial counts, some unicellular algae, some filamentous algae, waterweeds (Anacharis) and fish (Gambusia affins and Fundalus notatus).

Field and laboratory investigations were also concerned with the derivation and experimental validation of an expression to give the dissolved oxygen concentration during the critical night period for a small lake or pond treated with a 1:1 mixture of hexadecanol and octadecanol.

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Key Words: Evaporation Control / Monolayer Films/ Oxygen Diffusion* /Ecology* /Oxygen Deficiency / Hexadecanol* / Octadecanol*

INTRODUCTION

Clean fresh water is the most precious natural resource available to mankind. People must have water for personal, municipal, industrial and recreational use. At the present time, most of the available fresh water in the United States is used in some way or another, treated and returned to streams, rivers, lakes and reservoirs for reuse. Terrain, geographic location, climate and economics dictate that most of our usable fresh water be retained in lakes and reservoirs. This type of water storage allows for the greatest loss of water by evaporation.

The increasing demand for municipal, industrial and recreational fresh water has set in motion a vast impoundment program in the United States that will accelerate water evaporation control measures in the immediate future. According to Smerdon,[1] water loss by evaporation in the United States actually exceeds by over 10 times the total amount of water needed for municipal and industrial usage. In the United States alone, five billion acre-feet of water falls as precipitation each year. Of this amount over 3.5 billion gallons of water is returned to the atmosphere by evaporation or transpiration.

Americans are now consuming 355 billion gallons of water per day and this amount is expected to increase to 600 billion gallons per day by 1980. Home use of water represents less than 10% of the national consumption. Nearly half of the water is used for irrigation and the remaining 40% is used by industry.

Water conservation is a necessity in arid states that have scant rainfall and high evaporation losses. Eaton[2] reported that approximately 11.5 million acre-feet of water is lost due to evaporation each year in our eleven western states.

Scientists and engineers have considered many physical and chemical methods in an attempt to reduce water evaporation losses from lakes and reservoirs. One of the new and most promising techniques is the application of a thin chemical film on the surface of the water to retard evaporation.

An array of evaporation reduction chemicals has been utilized on reservoirs and lakes in different manners by Mansfield,[3] Cruse and Harbeck,[4] Timblin, Florey and Garstka,[5] and Meinke and Waldrip[6] to suppress evaporation and conserve water. One of the most promising of the current evaporation retardant chemicals is a blend of hexadecanol and octadecanol (Durham and McArthur).[7] These long-chain fatty alcohols form a monomolecular film on the water surface that is self-healing at wind speeds of up to eight miles per hour (Gilby and Heymann)[8] and is capable of reducing water evaporation by 30 to 50% under ideal conditions. According to Ludzack and Ettinger,[9] and Chang, et al.[10] the monolayer is biodegradable and can be assimilated by bacteria in the water as food.

According to Wiltzius,[11] hexadecanol and octadecanol are nontoxic and do not present a health hazard in potable water. However, research indicates that monolayers change some of the physical and

chemical characteristics in the treated aquatic environments. A monolayer will calm the water surface and form a slight diffusion barrier to the transfer of gases into and out of the water environment. The film will also decrease the surface tension of the water surface by 50% or more from a normal 60 to 72 dynes per centimeter to less than 40 dynes per centimeter. Furthermore, the film causes a slight temperature increase in the water immediately below the film. All of these factors may significantly affect the ecology of ponds, lakes and reservoirs.

While field studies have shown hexadecanol and octadecanol films to be successful in suppressing water evaporation, the ecological studies of such treated water have not been adequate. A comparative evaluation of the biological effects due to complete coverage of water by an evaporation retardant monolayer has not been possible under field conditions. The day-to-day environmental conditions of rapid temperature changes, wind, dust, rain, light fluctuations and other unpredictable factors do not allow a realistic evaluation of the ecological changes that may be caused by a continuous water-saving film.

The small laboratory ecosystem has long been a fundamental tool in the development of comparative ecology. These systems have also been called microcosms by Odum and Hoskins[12] and laboratory microecosystems by Beyers.[13] These small ecosystems may be used to study changes in water quality and population characteristics under controlled conditions obtained only in the laboratory. With the microcosm, one

does not experience the complexity, environmental variation, difficulty of replication, and handicap of sheer size presented by natural ecosystems. However, unnatural environmental conditions must be recognized when small laboratory ecosystems are used. Laboratory studies in experimental microcosms can not duplicate the complex ecosystem present in lakes and reservoirs. It is for this reason that field experiments were conducted on the latter phase of this research.

An intensive literature survey has revealed no prior attempt to evaluate the ecological and physical impact of a continuously applied evaporation reduction film on a laboratory experimental microcosm.

From past research, hexadecanol and octadecanol have proved to be the most promising chemicals for evaporation suppression. "Aquasave" which is a commercial mixture of roughly equal parts of octadecanol and hexadecanol has shown better evaporation reduction characteristics than either hexadecanol or octadecanol alone.[6] However, the effect of a monolayer of this chemical on oxygen transfer rate to the water has not been tested sufficiently.

The chemical, physical and biological effects of these alcohols have been studied to prove their suitability for evaporation suppression. However, there are conflicting viewpoints in the literature about the effect of a film of these alcohols on the oxygen transfer rate into the water. The diffusion of oxygen through these films has a special importance since any suppression of such diffusion may lead to oxygen stagnation in the reservoir thus setting up a potential anaerobic environment. On the other hand, although the reduction of oxygen transfer

rate due to the monolayer is small, it may be enough to maintain the oxygen content of the pond below the tolerance limit of the aquatic life. Another result of oxygen stagnation is the release of many ions (e.g. Fe^{++}) from the sediment to the water, as well as evolution of gases resulting from anaerobic bacterial action.

Among the many methods of application of the chemical is the solvent method. A solvent is used for dispensing the liquid form of "Aquasave" since "Aquasave" is solid at temperatures below 60°C. In this method the alcohol is dissolved in the organic solvent, then simply applied to the water surface. The method is simple and economical and its use in small lakes and ponds is ideal since other methods are more complicated and are seldom used by the pond owner.

In the near future the use of evaporation retardants will be shifted toward the small lakes and ponds since the studies on large reservoirs (e.g. Lake Hefner in Oklahoma) show a small reduction in the evaporation of the water. One of the reasons is the difficulty in covering the whole surface, which results in the presence of uncompressed monolayers and evaporation control is hindered.

In the previous studies of oxygen transfer rate through monolayers of hexadecanol and octadecanol, dissolved oxygen measurements were made without adequate controls and therefore these results cannot be reported with any degree of reliability. In addition, there were no attempts to find the effect of the organic solvent on oxygen transfer rate except for petroleum ether.[14] For these reasons, it is important to seek a better method of finding the effect of the monolayer as well as the solvent on the oxygen diffusion.

The objectives of this research have been to evaluate, under laboratory controlled conditions and field conditions the ecological and physical changes caused by the continuous application of a hexadecanol and octadecanol evaporation-suppression film.

This research has resulted in two Master of Science theses and one Ph.D. dissertation. Two technical reports have been issued by the Water Resources Institute and one paper has been given at the third national meeting of the American Water Resources Association. These reports are included in the reference section at the end of this final summary report.

This report is divided into two phases. The first phase is concerned with a laboratory investigation of the ecological effects of a 1:1 mixture of hexadecanol and octadecanol. The second phase is concerned with a laboratory and field investigation of the effects of a 1:1 mixture of hexadecanol and octadecanol on oxygen transfer. Part of this phase included an evaluation of the solvents used to disperse the monolayer.

EXPERIMENTAL PROCEDURES

Phase 1 - Ecological and Chemical Factors

Three consecutive thirty-day tests were run during the period May-September 1966. Chemical, physical and biological analyses were made on untreated and treated ecosystems. General limnological methods followed the procedures given by Welch[15] and Lagler.[16] Algae were identified following the keys in Ward and Whipple,[17] Needham and Needham,[18] and Palmer.[19]

The following three types of experimental ecosystems were used:

1. Two 20-gallon glass aquaria with a surface area (air-water interface) of 2.08 square feet (11.3" X 26.5"). Radiant energy was supplied by vertically adjustable banks of Sylvania "Gro-Lux" fluorescent lamps. Air and water temperature was identical. Water and algae collected in the field at the beginning of each experiment were innoculated into aerated tap water in both tanks at the ratio of one part mixed innoculum to twenty parts aerated tap water. One 20-gallon aquarium was filmed with a monolayer of "Aquasave" and the other untreated 20-gallon glass aquarium served as a control.

2. Eighteen 1-gallon wide mouth glass jars with a surface area (air-water interface) of 0.19 square feet for each jar. Radiant energy was supplied by vertically adjustable banks of Sylvania "Gro-Lux" fluorescent lamps. The jars were immersed to the jar neck in a large lucite water bath to maintain identical air and water temperature. Aerated tap water in all of the jars was innoculated with water and algae collected in the field at the beginning of each experiment.

[illegible] of the jars were filmed with "Aquasave" and the other nine untreated jars served as controls. Thus, eighteen 1-gallon jars were used for the first two of the three experimental series.

3. A large rectangular transparent lucite tank which was divided into two 20-gallon areas for the third series of experiments. Each side of the lucite aquarium has a surface area (air-water interface) of 3.55 square feet (16" X 32"). Vertically adjustable banks of Sylvania "Gro-Lux" fluorescent lamps supplied radiant energy. Aerated tap water in both tanks was innoculated with water and algae collected in the field at the beginning of the third test series. One side of the lucite tank was filmed with "Aquasave" while the other side served as a control.

Radiant energy intensity at the water surface was adjusted to 5,000 microwatts per square centimeter (approximately 520 foot-candles). The "Gro-Lux" light banks were controlled by timers to give 12-hour photoperiods (8 AM to 8 PM).

During all three series of tests, a continuous monolayer was maintained for each 30-day period at the dose rate equivalent to 0.05 pounds of "Aquasave" per day for each acre of treated water surface. The surface film was replenished every 24 hours to replace losses due to physical and biological breakdown.

All experimental ecosystems were innoculated at the beginning of each thirty-day experiment with mixed algal and water samples collected from three local ponds located in Brazos County. Innoculation was at the ratio of one part mixed innoculum to twenty parts aerated tap water.

The chemical analyses in this study were conducted using the [illegible] techniques outlined in Standard Methods for the Examination of Water and Wastewater.[20] The following chemical tests were made: hydrogen ion concentration; hardness; carbonate and bicarbonate alkalinity; turbidity; and dissolved oxygen.

In addition, diurnal oxygen measurements and primary productivity were used to study the community productivity and metabolism of the untreated and "Aquasave" treated aquaria. Four diurnal oxygen studies were conducted during each of the three experimental series.

Phase II - Physical Factors

The initial research procedure was developed to study the effects of the solvent on oxygen transfer by using the Gilson Respirometer. This instrument provides a direct comparison between the oxygen uptake rate of the samples with and without solvent.

The Gilson Respirometer (Model GRP-20) is described by Umbreit, et al.[21] and by the manufacturer as a differential respirometer in which the open arms of the twenty manometers are connected to a common compensation vessel through a manifold. This arrangement permits the simultaneous evacuation and gassing of all vessels and the compensating vessel eliminates corrections for barometric changes and minimizes temperature errors.

Accurate temperature control in the bath is provided by an electronic relay actuated by hermetically sealed thermoregulators. Temperature control accuracy is ± 0.02°C. Two heaters and refrigerators were provided to change the temperature of the water bath in relatively short time depending on the ambient temperature.

The data for this study were collected in three sets of experiments conducted at temperatures of both 21°C and 36°C. The first set of experiments consisted of deoxygenating four 20-liter glass bottles of distilled water. Two of the bottles were deoxygenated in a 21°C walk-in double-door incubator while the other two distilled water bottles were deoxygenated in a identical incubator kept at a temperature of 36°C. Each bottle of the deoxygenated distilled water was then transferred into a 20-gallon glass aquarium which had a surface area (air-water interface) of 2.08 square feet (11.3" X 26.5"). The depth of the water in each aquarium was 3.125 inches. Two aquaria were kept in the 21°C temperature incubator and the other two aquaria were kept in the 36°C incubator. One aquarium at each temperature was filmed with a monolayer of "Aquasave" while the other untreated aquarium served as a control. The increase in the dissolved oxygen concentration was then measured with respect to time until the water nearly reached the point of saturation.

In the second set of experiments, eight 20-liter bottles of "blended" water which contained 194 mg/l of total dissolved solids were deoxygenated identically the same as in the first set of tests. The blended water in four 20-liter bottles were deoxygenated in the 21°C incubator and then transferred to two glass aquaria in the same incubator. Similarly, "blended" water was deoxygenated in the 36°C incubator and transferred to two aquaria in the same incubator. The depth of the water in each aquaria in this set of tests was 6.25 inches. One aquarium at each temperature was filmed with a monolayer of "Aquasave" and the other untreated aquarium served as a control. The dissolved oxygen concentration was then measured with time until the water

nearly reached the point of saturation.

Water samples were collected from a local pond and tests were run to determine the amount of total dissolved solids in the water. The tests showed that the water in this particular pond has a total dissolved solids of 194 mg/l. Another test was conducted to find out the amount of total dissolved solids present in the College Station City water collected directly from the distribution system. The test showed the tap water contained 981 mg/l of total dissolved solids. Then a mixture of the tap water and distilled water was made to give the "blended" water with 194 mg/l total dissovled solids content. This blended water was used for the second set of experiments. In order to relate the results obtained from the second set of tests to the results from the third set of experiments, the water used in these two sets contained the same amount of total dissolved solids. The only difference in the water for the second and third sets of experiments would then only be the amount of algae and bacteria.

The third set of experiments was conducted mainly to determine the oxygen uptake rate of the algae and bacteria present in the local pond under this study and to verify the value of the most critical oxygen balance.

The dissolved oxygen concentration in Pond Number 8 of the Indian Lakes Resort was measured each 30 minutes from 2:00 AM until 7:00 AM. It was found that the lowest dissolved oxygen concentration occurred at 5:30 AM.

On a subsequent day a large quantity of water from the pond was collected at about 3:00 AM from several depths and several locations to insure a representative sample. The water was then brought into

the laboratory to test the oxygen uptake rate of the algae and bacteria present in the local pond under this study. Several 100 ml samples were drawn off from the pond water and each sample was placed in 125 ml reaction flasks. The reaction flasks were then immediately tested for the oxygen uptake rates by the use of a Gilson differential respirometer already described. Radiant energy was supplied by the lights in the respirometer. The intensity of the radiant energy was initially set at 1000 microwatts per square centimeter of water surface at 4:30 AM and was increased by 1000 microwatts per square centimeter each hour. The oxygen uptake rate was tested at a temperature of 21°C which was the same temperature measured in the pond at 5:30 AM the same morning.

The techniques used in operating the respirometer followed those outlined by Umbreit.[21] The "direct method" was used to absorb the CO_2 continuously. Folded KOH papers were inserted into alkali placed in the center wells of the reaction flasks. The center wells were greased at the top to prevent alkali creep. Twenty percent KOH was used to provide sufficient CO_2 uptake. Reduction in oxygen pressure due to algal respiration and bacterial action was measured in microliters of oxygen. From these data the uptake rate for the pond was calculated by a graphical method.

The pond, located fifteen miles south of College Station, Texas, is approximately ten years old and is designated Pond Number 8 in a private resort area called Indian Lakes. This pond was studied continuously from February through May of 1967. Temperature profiles, Secchi disc readings and dissolved oxygen concentration measurements were taken weekly on the pond.

The techniques selected to determine the oxygen transfer coefficient (K_L) for the first and second sets of experiments in this study follow the techniques published by the Twenty-Ninth Progress Report of the Committee on Sanitary Engineering Research of the Sanitary Engineering Division of the American Society of Civil Engineers.[22] A large sample of water (40 liters) was deoxygenated by bubbling a stream of gaseous nitrogen through it. Then, under quiescent conditions in aquaria, the water was allowed to absorb oxygen from the overlying atmosphere until an equilibrium was nearly established between the water and the atmosphere. The oxygen transfer coefficient was then determined as the slope of the log of the concentration deficit curve vs time plotted on semi-log paper using saturation of oxygen as the baseline.

RESULTS AND CONCLUSIONS

The pH data shown in Figure 1 indicate a higher reading for untreated water as compared with treated systems. Figure 2 shows a comparison between untreated and treated aquatic systems with no significant difference in bicarbonate and carbonate alkalinity.

Figure 3 shows a diurnal oxygen curve and illustrates the oxygen deficiency existing between untreated and treated aquatic systems. The dissolved oxygen data also show that one oxygen determination a day is not satisfactory for working with growing biomass and diurnal oxygen curves must be used to examine the photosynthetic and respiratory process that occurs in aquatic ecosystems. The data also indicate that a potential danger exists in natural water treated with hexadecanol and octadecanol due to low oxygen content in the water during the night respiration period. Such oxygen deficiency in treated waters may be due to bacterial growth, photosynthetic blockage, gas diffusion or a combination of biological and chemical factors.

No chlorophyll buildup or energy storage release is reflected in the oxygen measurement in the treated systems after the light energy is turned off. The energy release curve shown in the untreated oxygen curve after the lights were turned off is more normal since chlorophyll synthesis and oxygen production will rise slightly from stored energy after a decrease in maximum usable energy input. Equal amounts of the same species of algae and other biomass were present in the compared systems but oxygen buildup was much less in the systems treated with "Aquasave".

Standard plate counts of bacteria show a marked difference between the untreated and treated systems. Figure 4 shows the treated waters are supporting 3,500 more bacterial colonies per ml than the untreated waters.

From visual examinations, the water in the treated systems appears clearer from the water surface since the algal mats are not floating naturally at the water surface but resting on the bottom of the aquaria. However, glass side containers and turbidity measurements show that the treated water is more turbid with unicellular algae than the untreated water as shown in Figure 5. The turbidity curves closely follow the growth curves of the green algae Chlorella in the untreated and treated systems. Water clarity is affected by biological breakdown of the hexadecanol and octadecanol monolayer. The film accelerates bacterial growth which in turn assists algal growth. However, without normal surface tension, the filamentous algal mats increased unicellular and filamentous algal growth will add positive ions to the aquatic system which can combine with the negative charged amphoteric clay particles and cause the silt to settle to the bottom of such treated water. Both algal growth and turbidity measurements are reflected in Aquatic Systems by lowering the water hardness as shown in Figure 6.

Figure 7 shows two different growth curves for the green alga Chlorella. A rapid growth peak and decline is shown in the untreated systems. However, the algal growth is suppressed in the treated systems until the end of the first week. The unicellular algae then increase rapidly in cell numbers. Chlorella is the algal growth causing water turbidity in the continuously filmed aquatic systems.

Figure 8 shows a comparision between the growth curves of the green algae Ankistrodesmus. This population increase is much like the population increase shown in the growth curves of Chlorella. The untreated and treated algal Ankistrodesmus and Chlorella populations can be correlated with the turbidity measurements in Figure 5.

The green algae Scenedesmus is compared by growth increase in Figure 9. The treated system supported a larger population than the untreated waters.

A decrease in the diatom population in both untreated and treated aquatic systems is shown in Figure 10.

A chlorophyll analysis was made to compare the net primary productivity between the untreated and treated systems. Measurements were made with a Coleman Model EPS-3T Hitachi Spectrophotometer. Figure 11 shows the greater chlorophyll buildup in the treated systems when compared with the untreated systems.

Microscopic study and photomicrographs of algae in the untreated and treated systems show a growth contract. Algal mats of filamentous algae rose to the surface of the untreated waters and remained in such position for the duration of the experiments. However, filamentous algae in the "Aquasave" treated systems sank to the bottom of the aquaria and did not rise to the surface at any time. Such action may be brought about by the reduction of surface tension in the treated systems.

Bacterial clumping was evident in the treated filamentous algae and algae attached to the walls of the aquaria. Some chloroplast breakdown was observed in algae cells in the untreated system when compared with the same species in the treated systems. However, blockage of

usable chlorophyll could influence the low dissolved oxygen production in the treated systems.

Filamentous algae were compared for net primary productivity by the harvest method. Figure 12 shows the difference between the untreated and treated aquatic microcosms. The biomass of the waterweed Anacharis decreased about the same amount in both untreated and treated systems. No significant difference was found in dry weight-ash weight measurements of filamentous algae.

The oxygen transfer rate is simply calculated by taking the average reading of every set of flasks and dividing that by the time elapsed to determine the rate of oxygen transfer at that instant.

Tables 5 and 6 show samples of data obtained by the Gilson and the calculated oxygen transfer rates. The results of the effect of a compressed monolayer of aquasave on oxygen transfer rate are tabulated in Table 7. Table 8 shows the results of the reduction of oxygen transfer rate due to application of isopropyl alcohol, kerosene, n-pentanol, n-Hexane and petroleum ether as organic solvents. These results are shown graphically in Figures 20 - 25.

The results and conclusions may be summarized as follows:

Hardness: No significant difference in water hardness was noted between the treated and untreated systems. As shown in Table 1, it appears that a continuous monolayer of "Aquasave" would not affect water hardness.

Primary Productivity: A continuous monolayer of "Aquasave" was found to decrease the oxygen transfer, inhibit algal growth and reduce

primary productivity for a "short term" effect (1 to 15 days) when compared with the algal growth (same forms) and primary productivity in the untreated systems. However, over a longer term (15 to 30 days), the systems treated with "Aquasave" displayed higher oxygen values, increased the growth of some algal species and increased primary productivity when compared to the controls. This shows that a monolayer will inhibit primary productivity on the "short term" basis and encourage algal growth and primary productivity over a "long term" basis under the conditions used in this study.

The diurnal oxygen methods and the chlorophyll analysis methods were used for measuring and comparing the primary productivity. Figures 13 through 16 give the complete results of productivity in the treated and untreated systems for one of the experiments. The other two experiments gave essentially the same results. Figure 17 compares the net primary productivity in the untreated and treated systems as found by the chlorophyll analysis. The chlorophyll analyses for the two other experiments taken after the duration of the experiments show generally the same results as Figure 17. The results of the chlorophyll analyses indicate that a significant primary productivity increase occurred in the systems treated with "Aquasave". It appears then that the biological population in the treated systems benefited indirectly from the film application.

Bacteria: The data collected for the three thirty-day replicate tests show that bacteria increase in microcosms treated with a continuous monolayer of "Aquasave". The major bacterial growth was immediately under the "Aquasave" film. The comparison of bacteria colonies is

shown for one set of the experiments in Figure 18. The bacterial colonies counted from the other two experiments are in essential agreement with the data shown in Figure 9. Biological degradation of the evaporation suppressant film resulted in increased growth in bacterial populations. A significant increase in the growth of bacteria was found for all three thirty-day experiments. Bacterial increase caused by a monolayer of "Aquasave" could present a problem by demands on a limited oxygen supply.

Algae: Biotic changes in the experimental ecosystems were evaluated by comparison and enumeration of phytoplankton populations in untreated and treated systems. Nonfilamentous algae in the untreated systems were found to increase in numbers during the first half of all experiments. Nonfilamentous algae in the systems treated with "Aquasave" seemed to have inhibited growth for the first half of the thirty-day experiments, but increased in numbers during the latter half of the experiments. At the conclusion of all experiments, the growth of the nonfilamentous algae in the systems treated with "Aquasave" were significantly higher than the numbers of the same algal forms found in the untreated systems.

Filamentous algae in the systems treated with a monolayer had better growth than the same algae in the untreated systems (See Figure 19 and Table 2 for results). The Chlorella cell counts for the other two experiments were generally in the same agreement as the data shown in Figure 19.

Anacharis: A monolayer of "Aquasave" was detrimental to the growth of the waterweed Anacharis. Less new growth was found for the Anacharis in the treated systems (See Table 3).

Fish: As shown in Table 4, no significant effect of "Aquasave" was noted for two species of fishes, Gambusia affinis and Fundulus notatus. Observations indicate that the indirect effect of dissolved oxygen deficiencies could prove dangerous to fish life.

The results of the reoxygenation experiments to determine the K_L and K_L' values by the dissolved oxygen analyzer are shown in Table 9. The results indicate a reduction in 0.005 ft/hr in the oxygen transfer coefficient for water of 21°C temperature and treated with "Aquasave". As shown in Table 1 for Dissolved Oxygen Meter data, the transfer coefficient at 21°C, K_L, was found to be 0.0192 ft/hr (0.644 cm/hr) for untreated distilled water while the same treated water showed a K_L' value of 0.0142 ft/hr (0.433 cm/hr).

An investigation with the same distilled water under a temperature of 36°C revealed a reduction of 0.0059 ft/hr in the transfer coefficient for water treated with "Aquasave". As shown in Table 1, the transfer coefficient for treated distilled water was found to be 0.0315 ft/hr (0.452 cm/hr) at 36°C while the untreated distilled water showed a K_L value of 0.0374 ft/hr (0.452 cm/hr). Since the reduction in the transfer coefficient at 21°C, 0.005 ft/hr is approximately the same as the reduction in the coefficient at 36°C, 0.0059 ft/hr, it appears that the reduction is fairly independent of the temperature.

Data on the oxygen transfer coefficients are shown graphically in Figures 26 through 33.

The results shown in Table 9 using water which contains 194 mg/l total dissolved solids, show the mass transfer rate coefficient to be less for water treated with "Aquasave" than water with no treatment.

This observation was true for water at both 21°C and 36°C temperatures. The reduction in the transfer rate coefficient at 21°C was found to be 0.0014 ft/hr while at 36°C, it was 0.002 ft/hr. Since these two values are also approximately equal, as was found with the distilled water, the concept that the reduction in transfer rate coefficient is fairly independent of the temperature is further supported.

In order to compare the oxygen transfer coefficient of water treated with "Aquasave", K_L', to that of water with no treatment, K_L, a coefficient n is defined as the ratio of K_L' to K_L under exact conditions of temperature and mineral content of the water. For distilled water at 21°C, n was found to be 017 while for the same water at 36°C, it was found to be 0.8. In the water which contained 194 mg/l dissolved solids n had a value of 0.9 at both 21°C and 36°C temperatures. In comparing the values of n for distilled water and water with dissolved solids, it should be pointed out that these results are in general agreement with results reported in the literature. Many dissolved impurities have been shown to affect the rate of oxygen diffusion into the water although the magnitude of the observed effects depends on the nature and concentration of these contaminants. To get a general idea of the magnitude of such effects, each water should be analyzed in order to determine its exact K_L' and K_L values.

The effects of temperature on the K_L value are expressed in the following equation:

$$K_T = K_{20} (\theta)^{T-20}$$

where $K_T = K_L$ value at temperature, T, and $K_{20} = K_L$ at 20°C. This same type of equation can be used to express the effects of temperature upon the K_L' values.

There is no single value of θ which can represent the entire spectrum of mixing conditions. Therefore, θ would have to be a variable in the equation above, constant values being applicable only over certain ranges of turbulence.

Since this study was conducted under quiescent conditions for both 21°C and 36°C temperatures, θ may be calculated from the results by assuming K_L and K_L' at 21°C to be nearly equal to K_L and K_L' at 20°C, respectively. Therefore, θ was calculated on this basis and found to be 1.0456 for the untreated distilled water and 1.0475 for untreated "blended" water. For the treated distilled water, θ was calculated to be 1.0546 while for the treated "blended water, θ was calculated to be 1.0502.

The results of this study have also shown that a compressed monolayer of "Aquasave" at 30°C suppresses the oxygen transfer rate to the liquid phase by 18 to 33 percent. This reduction is due to the increase of the interfacial resistance due to the presence of a monolayer film. In practice such reduction may prohibit the use of "Aquasave" to retard evaporation in water bodies where oxygen stagnation is probable.

A more important factor in reducing the oxygen transfer is the solvent used to dispense the "Aquasave" monolayer. The result of this study shows that isopropyl alcohol and n-pentanol reduce the transfer of oxygen to a great extent. For this reason, isopropyl alcohol and n-pentanol are not recommended to be used as solvents.

Kerosene did not affect oxygen transfer if used in small amounts, but since the evaporation of kerosene is very slow, it will accumulate over the water surface and will buildup a layer which will retard oxygen transfer to the water in addition to the other effects.

Hexane, when present in solution with water, reduces the oxygen transfer rate, but the probability of the presence of hexane in water as a solution is low because of the slight solubility and the high volatility of n-hexane. The factor which will limit the use of this solvent in practice is its high cost.

Petroleum ether does not affect oxygen transfer rate and this result sustained Blank's findings[14] on the effects of petroleum ether on oxygen transfer rate into chemically reactive solutions. The solvent looks to be ideal for use in practice and it is inexpensive.

In addition, field and laboratory data can be summarized as follows:

An oxygen balance to determine the minimum dissolved oxygen concentration, C, in the early morning hours in a selected lake which contains algae, bacteria and other organisms can be represented by the equation,

$$K_L \frac{A}{V} (C_s - C) = r \quad \text{Equation (14) in Appendix}$$

where

K_L = oxygen transfer coefficient

A = lake surface area

V = lake volume

C_s = saturation dissolved oxygen concentration

C = minimum dissolved oxygen concentration

r = oxygen uptake rate

This equation was verified for a selected lake by knowing all values except C, which was measured in the field. The field value of C was approximately equal to the computed value of C.

In using Equation (14), the lake must be less than approximately 25 feet in depth to avoid an appreciable oxygen gradient.

The oxygen transfer coefficient in distilled water treated with "Aquasave" at 21°C was 74 percent of coefficient of the untreated water while in the same water at 36°C, the transfer coefficient for the treated condition was 84 percent of the coefficient for untreated water.

In determining the effects of dissolved solids on the oxygen transfer coefficient, it was found that for water from the selected lake used in this study, which contained 194 mg/l dissolved solids, the coefficient for water treated with "Aquasave" at 21°C was 89.6 percent of the coefficient for untreated water, while in the same water the coefficient at 36°C for the treated condition was 92.6 percent of the coefficient for untreated water.

A relationship was found to give the oxygen transfer coefficient at any temperature for both treated and untreated water by the following equation:

$$K_T = K_{20} (\theta)^{T-20}$$ (From Reference 29)

where K_T = the transfer coefficient at any temperature, K_{20} = the coefficient at 20°C and T = temperature in Centigrade. θ for untreated water was found to be approximately 1.047 and for the treated water θ was 1.053.

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APPENDIX

The dispersion of oxygen from the atmosphere through a body of liquid is accomplished by the process of diffusion. This process tends to produce a stable state of uniform concentration (i.e., equilibrium). In an atmospheric oxygen-water system, the mass transfer by diffusion between the gas phase and liquid phase is due to a driving force created by a departure from the equilibrium state. This driving force is a partial pressure gradient in the gas phase and a concentration gradient in the liquid phase. The rate of molecular diffusion of a dissolved gas in a liquid is dependent on the characteristics of the gas and liquid, the temperature, the concentration gradient and the cross-sectional area through which diffusion occurs.

Fick's Law of Diffusion

Fick's Law defines the diffusion process as:

$$\frac{dm}{dt} = D_L A \frac{dc}{dy} \qquad (1)$$

in which dm/dt represents the time rate of mass transfer by diffusion, A is the cross-sectional area through which diffusion occurs, dc/dy indicated the concentration gradient (mass/unit volume/unit length) in the direction perpendicular to the cross-sectional area, and D_L denotes the diffusion coefficient for oxygen in water. D_L is expressed as per unit time.

Lewis and Whitman Concept of Two Films

The mass transfer of a gas from the atmosphere to the body of a fluid may also be expressed in the differential form by the two

film concept of Lewis and Whitman[23] which is similar to Fick's Law. Lewis and Whitman's equation is:

$$\frac{dm}{dt} = - D_g A \left[\frac{\partial c}{\partial y}\right]_1 = - D_L A \left[\frac{\partial c}{\partial y}\right]_2 = - D_e A \left[\frac{\partial c}{\partial y}\right]_3 \qquad (2)$$

in which,

$\left[\frac{\partial c}{\partial y}\right]_1$ = concentration gradient through the gas film

$\left[\frac{\partial c}{\partial y}\right]_2$ = concentration gradient through the liquid film

$\left[\frac{\partial c}{\partial y}\right]_3$ = concentrationd gradient in the body of liquid below the film

D_g = molecular diffusivity of the gas through the gas film

D_L = molecular diffusivity of the gas through the liquid film

D_e = eddy diffusion coefficient of the gas in the body of the liquid

The value of the eddy diffusion coefficient is the same order of magnitude as that of the eddy viscosity of the liquid, which depends upon the physical and hydraulic characteristics of the system. The physical set-up of the experiment in this study was such that the concentration of dissolved oxygen throughout the depth of water was uniform and therefore eddy diffusivity was not the limiting resistance.

Since the diffusion in the gaseous phase is usually 10^4 times faster than in the liquid phase,[24, 25] and the entire gradient is

assumed to exist at the interface, it may therefore be concluded from these considerations that in the transfer of a sparingly soluble gas such as oxygen, the controlling resistance is in the liquid film, and Equation (2) may be re-expressed as follows:

$$\frac{dm}{dt} = \frac{D_L}{y_L} A (C_s - C) \qquad (3)$$

where y_L is the hypothetical film thickness, C_s is the saturation concentration of the gas in the liquid surface at the temperature and pressure of the experiment and C is the concentration in the bulk liquid.

Equation (3) may also be expressed in terms of a liquid film coefficient as follows:

$$\frac{dm}{dt} = K_L A (C_s - C) \qquad (4)$$

where K_L is defined as the diffusivity, D_L, divided by the hypothetical liquid film thickness, y_L.

Resistances Equation

Obviously, then, a new coefficient is required to represent the total mass transfer coefficient in the liquid phase when the surface of the liquid is covered with the monomolecular film. Designating K_s as the transfer coefficient for the "Aquasave" monomolecular film, and K_L as the transfer coefficient in the absence of "Aquasave", the total transfer coefficient, K_L', will be defined in terms of resistances by the following equation:

$$\frac{1}{K_L'} = \frac{1}{K_L} + \frac{1}{K_s} \qquad (5)$$

in which $\frac{1}{K_L}$ represents the resistance to mass transfer in liquid phase during the absence of any "Aquasave" film, $\frac{1}{K_s}$ denotes the resistance due to the monomolecular film of "Aquasave", and $\frac{1}{K_L'}$ is the total resistance to mass transfer in the liquid phase.

Evaluation of Transfer Coefficients

Equation (4) may be expressed in concentration units by introducing the volume of the liquid:

$$\frac{1}{V}\frac{dm}{dt} = \frac{dc}{dt} = K_L \frac{A}{V} (C_s - C) \qquad (6)$$

Equation (6) shows that the rate of gas transfer, $\frac{dc}{dt}$, is proportional to the concentration gradient, the ratio of interfacial area to the liquid volume and the mass transfer coefficient K_L.

Multiplying Equation (6) by $\frac{dt}{C_s - C}$ will give,

$$\frac{dc}{C_s - C} = K_L \frac{A}{V} dt \qquad (7)$$

and integrating with respect to time and concentration, Equation (7) will give the following equations:

$$\int_{C_o}^{C_t} \frac{dc}{C_s - C} = K_L \frac{A}{V} \int_o^t dt \qquad (8)$$

$$\ln \frac{C_s - C_t}{C_s - C_o} = -K_L \frac{A}{V} t \qquad (9)$$

$$\ln (C_s - C_t) - \ln (C_s - C_o) = -K_L \frac{A}{V} t \qquad (10)$$

$$\ln (C_s - C_t) = -K_L \frac{A}{V} t + \ln (C_s - C_o) \qquad (11)$$

Hence, a plot of $\ln (C_s - C_t)$ against time, t, should result in a straight line with a slope equal to $-K_L \frac{A}{V}$.

K_L' is evaluated in an identical manner by substituting K_L' in Equation (4), and thus the following equation is easily derived:

$$\ln (C_s - C_t) = -K_L' \frac{A}{V} t + \ln (C_s - C_o) \qquad (12)$$

By knowing the values of K_L for a quiescent body of water without any "Aquasave" film and K_L' during the presence of a monomolecular film of "Aquasave", the values of K_s are therefore easily obtained from Equation (5).

Lake Water Ecological Systems

A lake contains many living organisms such as algae, bacteria, both in the water and on the bottom sediments, fish and other organisms. All organisms except algae use oxygen at approximately the same rate during a 24 hour day period. During the day algae produce oxygen while at night time they utilize oxygen. This phenomenon causes the dissolved oxygen concentration to fluctuate during a diurnal period. During the day the oxygen concentration may be extremely high, however, during the night the oxygen concentration begins to drop. The concentration reaches a minimum during the early hours of the morning. This minimum has been found to occur between

5:30 to 6:30 AM during the summers in Texas.[26] The critical time of the year is the summer period since algal growth and bacterial growth are at a maximum and the dissolved oxygen saturation value is at a minimum.

The dissolved oxygen concentration under unsteady-state conditions is represented by the differential equation,

$$\frac{dc}{dt} = K_L \frac{A}{V} (C_s - C) - r \qquad (13)$$

where r represents the oxygen uptake rate.[27]

During the critical early morning hours, the change in oxygen uptake, dc, per unit time, dt, becomes zero and a steady-state condition is reached. For steady-state with $\frac{dc}{dt} = 0$, Equation (13) becomes,

$$r = K_L \frac{A}{V} (C_s - C) \qquad (14)$$

If r can be determined and K_L, A, V and C_s are known for a lake, then the critical dissolved oxygen concentration in the lake, C, can be evaluated from Equation (14).

To determine the effect of "Aquasave" upon a lake, r' and K_L' must be determined and hence the minimum dissolved oxygen concentration can be calculated from Equation (14). In this calculation, K_L', will be used in place of K_L in Equation (14).

It is recognized that in determining the minimum dissolved oxygen concentration, C, it is assumed that the oxygen concentration in a lake is fairly uniform throughout the depth. The zones of water movement, the epilimnion and the mesolimnion usually have a low oxygen

gradient. These zones extend down to a maximum of approximately 20 feet. The measurements made on Lake Austin, Texas[28] during the summer of 1963 showed a very low oxygen gradient down to its maximum depth of approximately 25 feet at that time. The lake was fairly quiescent at the time of the measurements.

TABLE I

CHEMICAL ANALYSES OF WATER FROM UNTREATED AND TREATED EXPERIMENTAL ECOSYSTEMS DURING THE TIME INDICATED. ALL DATA GIVEN AS MILLIGRAMS PER LITER.

LEGEND

o Untreated

Δ Treated with 0.05 pounds of "Aquaseve" per acre of water

Test Series	Time in Days	Hardness as $CaCO_3$ o	Hardness as $CaCO_3$ Δ	Carbonate Alkalinity o	Carbonate Alkalinity Δ	Bicarbonate Alkalinity o	Bicarbonate Alkalinity Δ
"A" 26 May to 24 June 1966	1	11	11	16	16	218	218
	.6	12	16	52	24	210	224
	12	12	18	52	26	210	208
	18	12	16	60	40	226	238
	24	10	13	54	62	233	244
	30	9	12	40	76	266	262
"B" 20 July to 18 Aug. 1966	1	26	26	56	56	272	272
	6	28	32	28	36	306	306
	12	34	26	56	40	286	334
	18	16	22	42	64	342	342
	24	12	10	48	52	346	380
	30	14	14	36	40	426	440
"C" 24 Aug. to 22 Sept. 1966	1	8	8	16	16	266	266
	6	12	10	18	12	254	246
	12	12	10	24	20	256	270
	18	10	16	40	32	270	258
	24	10	12	52	44	260	258
	30	11	12	60	52	288	274

TABLE 2

A COMPARISON OF FILAMENTOUS ALGAE GROWTH IN UNTREATED AND TREATED AQUATIC EXPERIMENTAL ECOSYSTEMS AT THE CONCLUSION OF THE INDICATED THIRTY-DAY TEST. GROWTH IS EXPRESSED IN GRAMS.

LEGEND

ȯ Untreated

Δ Treated with 0.05 pounds of "Aquasave" per acre of water

Test Series	Cladophora		Chara		Anabaena	
	ȯ	Δ	ȯ	Δ	ȯ	Δ
"A" 26 May to 24 June 1966	22	55	6	9	-	-
"B" 20 July to 18 Aug. 1966	8	22	4	13	-	-
"C" 24 Aug. to 22 Sept. 1966	5	10	3	9	4	5

TABLE 2

A COMPARISON OF FILAMENTOUS ALGAE GROWTH IN UNTREATED AND TREATED AQUATIC EXPERIMENTAL ECOSYSTEMS AT THE CONCLUSION OF THE INDICATED THIRTY-DAY TEST. GROWTH IS EXPRESSED IN GRAMS.

LEGEND

ò Untreated

Δ Treated with 0.05 pounds of "Aquasave" per acre of water

Test Series	Cladophora		Chara		Anabaena	
	ò	Δ	ò	Δ	ò	Δ
"A" 26 May to 24 June 1966	22	55	6	9	-	-
"B" 20 July to 18 Aug. 1966	8	22	4	13	-	-
"C" 24 Aug. to 22 Sept. 1966	5	10	3	9	4	5

TABLE 3

A COMPARISON OF THE ANACHARIS (ELODEA) GROWTH GAIN OR LOSS IN UNTREATED AND TREATED AQUATIC EXPERIMENTAL ECOSYSTEMS AT THE CONCLUSION OF THE INDICATED THIRTY-DAY TEST.

LEGEND

ó Untreated

Δ Treated with 0.05 pounds of "Aquasave" per acre of water

Test Series	"A" 26 May to 24 June 1966	"B" 20 July to 18 August 1966	"C" 24 August to 22 Sept. 1966
o Untreated	+ 10 grams	+ 7 grams	+ 3 grams
Δ Treated	+ 5 grams	+ 1 gram	- 4 grams

TABLE 4

THE NUMBER OF DEATHS RECORDED FOR TWO SPECIES OF FISHES IN UNTREATED AND TREATED AQUATIC EXPERIMENTAL ECOSYSTEMS AT THE CONCLUSION OF THE INDICATED THIRTY-DAY EXPERIMENT.

LEGEND

o Untreated

Δ Treated with 0.05 pounds of "Aquasave" per acre of water

Note. Six Gambusia affinis and six Fundulus notatus were introduced into each 20-gallon aquarium prior to the beginning of each experiment.

Test Series	"A" 26 May to 24 June 1966		"B" 20 July to 18 August 1966		"C" 24 August to 22 Sept. 1966	
	o	Δ	o	Δ	o	Δ
Gambusia affinis	0	3	1	2	2	1
Fundulus notatus	1	1	0	0	2	0

TABLE 5

Data Sheet Form of Gilson Readings

Reagent: n-Pentanol
Temperature: 30°C
System: Open

Date: September 18, 1966

Time Minutes	O_2 Uptake in Microliters											
	#1 .2 µl	#3 .2µl	#4 .2µl	#5 2 µl	#6 2 µl	#7 2 µl	#10 Cont	#11 Cont	#12 Cont	#13 10 µl	#14 10 µl	#15 10 µl
0	[1] 10	10	10	10	10	10	10	10	10	10	10	10
12	[2]246	287	246	158	142	148	352	350	336	79	86	76
20	10	10	10	10	10	10	10	10	10	10	10	10
30	207	245	209	131	116	123	303	305	288	67	70	63
40	10	10	10	10	10	10	10	10	10	10	10	10
50	207	237	208	130	119	124	292	301	282	70	76	65
55	10	10	10	10	10	10	10	10	10	10	10	10
[4]65	212	242	216	138	125	133	296	305	284	77	80	72
245	10	10	10	10	10	10	10	10	10	10	10	10
255	191	197	180	122	113	116	223	234	221	70	77	67

[1] Initial micrometer reading at the beginning of the timing.

[2] Final reading after 12 minutes (elapsed time for this particular reading).

[3] The micrometer is readjusted again to read 10.

[4] Data were collected during the interval but not shown in this table.

TABLE 6

Form of the Calculated Transfer Rate
From the Gilson Data in Table 5

Time Minutes	O_2 Transfer Rate in $\mu l/min/in^2$			
	Control	0.2 µl Dosage	2.0 µl Dosage	10 µl Dosage
6	[1]7.0	5.2	2.9	1.5
25	7.2	5.2	2.8	1.5
45	7.0	5.2	2.8	1.5
60	7.1	5.3	3.0	1.7
80	6.8	4.9	2.8	1.4
100	6.1	4.5	2.5	1.3
190	5.6	4.3	2.6	1.3
250	5.4	4.5	2.7	1.5

[1]The O_2 transfer rates shown in this table were calculated as follows: From Table 3 the average O_2 uptake for the controls is equal to

$$\frac{(352 - 10) + (350 - 10) + (336 - 10)}{3} = 336 \ \mu l$$

and the elapsed time is 12 minutes. The surface area of the solution in the reactor is 4 in^2. The O_2 transfer rate is therefore equal to

$$\frac{336}{12 \times 4} = 7.0 \ \mu l/in^2/\ min$$

TABLE 7

[1]The Effect of Aquasave Monolayer on O_2 Uptake Rate

Trial	Initial O_2 Uptake Rate in $\mu l/min/in^2$		[2]Final O_2 Uptake Rate in $\mu l/min/in^2$		Avg. Reduction in O_2 Transfer Rate	
	[3]Control	[4]Sample	Control	Sample	Pct.	$\mu l/min/in^2$
1	7.0	5.5	6.0	5.2	13%	1.15
2	8.0	6.5	7.2	6.2	17%	1.25
3	9.5	6.7	7.3	6.3	22%	1.90
4	8.5	7.0	7.5	6.6	15%	1.20
5	5.4	3.5	4.5	3.4	24%	2.00

[1]All the experiments were run under closed systems at 30°C.

[2]This final is taken after 4 hours except for trial #1 which was taken after 2 hours.

[3]The control is treated with the same amount of solvent used in the sample (5 ul hexane in all trials except #1 [0.1 ml]).

[4]The sample is treated with a dosage of 1.04 mg/ft^2 aquasave dissolved in 5 ul hexane (#1 treated with .52 mg/ft^2 dissolved in 0.1 ml hexane).

TABLE 8

Results of the Effect of Organic Solvents on O_2 Transfer Rate

Solvent	Dose		Initial O_2 Uptake Rate µl/min/in^2		Final O_2 Uptake Rate µl/min/in^2		Average Reduction		Standard Deviation of O_2 Reduction
	µl	ppm	control	sample	control	sample	µl/min/in^2	%	µl/min/in^2
Isopropyl alcohol	0.05	1	7.2	6.2	5.9	5.7	0.85	13	.....
	0.20	4	8.1	5.3	5.2	4.3	1.85	28	.....
	0.50	10	7.3	3.7	5.6	3.7	2.7	42	±.05
	2.00	40	7.3	2.1	5.6	2.5	4.2	65	±.2
	5.00	100	7.3	1.3	5.6	1.8	4.9	76	0
Kerosene	0.5	10	No indication of O_2 transfer reduction						
	2.0	40	No indication of O_2 transfer reduction						
	10.0	200	No indication of O_2 transfer reduction						
	50.0	1000	No indication of O_2 transfer reduction						
n-Pentanol	0.2	4	6.3	4.8	5.0	4.2	1.2	20	±0.1
	2.0	40	6.3	2.6	5.0	2.7	3.0	53	±0.1
	10.0	200	6.3	1.4	5.0	1.4	4.2	74	0
n-hexane	0.1	2	No indication of O_2 transfer reduction						
	2.0	40	No indication of O_2 transfer reduction						
	10.0	200	9.8	9.1	6.4	6.2	.5	6	0
	100.0	2000	10.0	7.0	6.5	4.9	2.3	28	.....
Petroleum ether	.1	2	No indication of O_2 transfer reduction						
	2.0	40	No indication of O_2 transfer reduction						
	10.0	200	No indication of O_2 transfer reduction						

TABLE 9

Summary Table For The Oxygen Transfer Coefficient For Treated And Untreated Water. Measurements Are Made By D. O. Meter. Units Of Coefficients Are In Ft./Hrs.

K_L': Treated K_L: Untreated

Liquid Film Coefficient	At 21°C Using Distilled Water	At 21°C Using Blended Water	At 36°C Using Distilled Water	At 36°C Using Blended Water
K_L'	0.0142	0.0121	0.0315	0.0251
K_L	0.0192	0.0135	0.0374	0.0271
$1/K_L'$	70.4225	82.6446	31.7460	39.8406
$1/K_L$	52.0833	74.0741	26.7380	36.9004
$1/K_L' - 1/K_L$	18.3392	8.5707	5.0080	2.9402
$1/K_s$	18.3392	8.5707	5.0080	2.9402

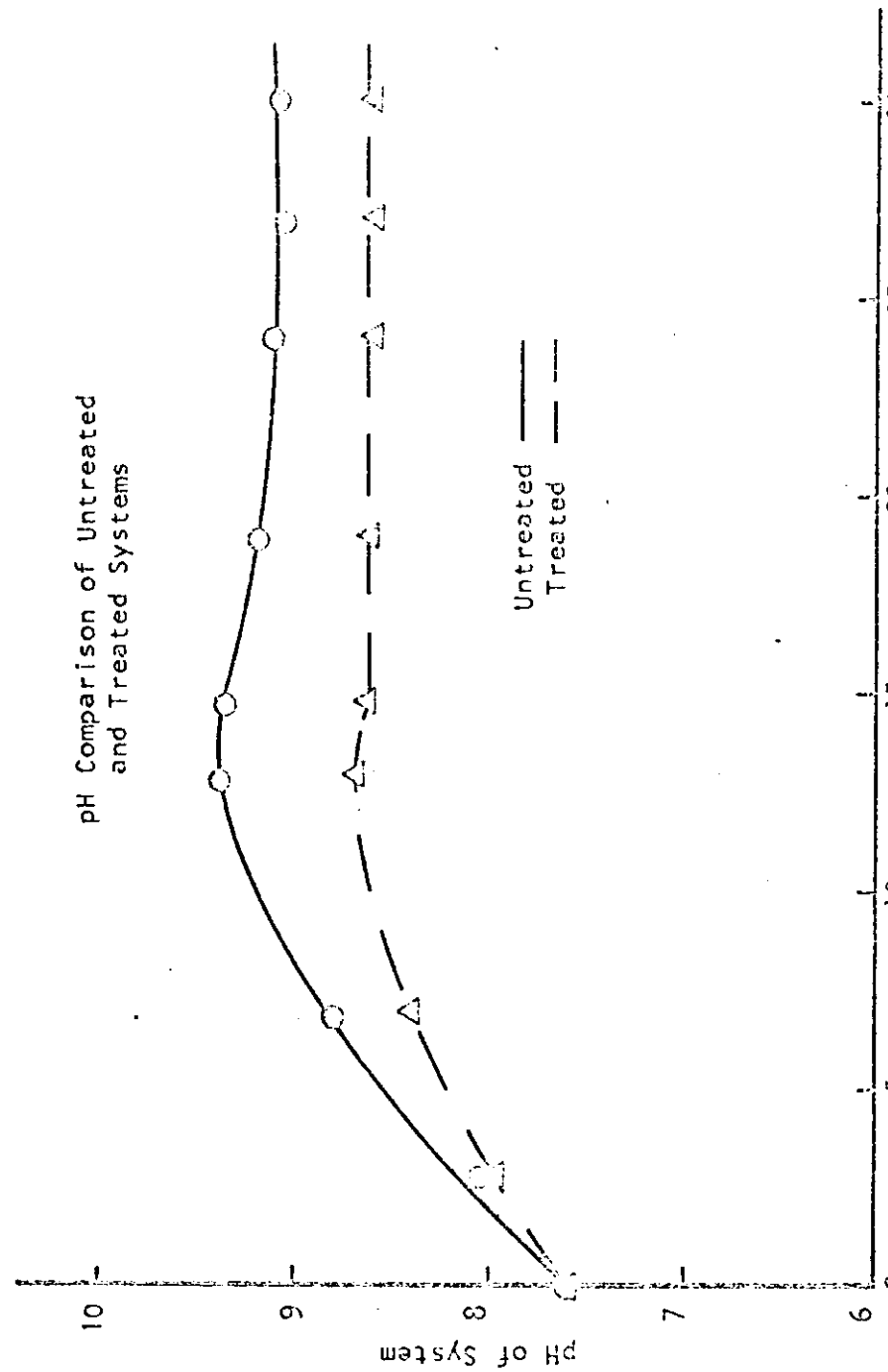

pH Comparison of Untreated and Treated Systems
Untreated
Treated
pH of System
Time in Days
10
9
8
7
6
0
5
10
15
20
25
30

Figure 1

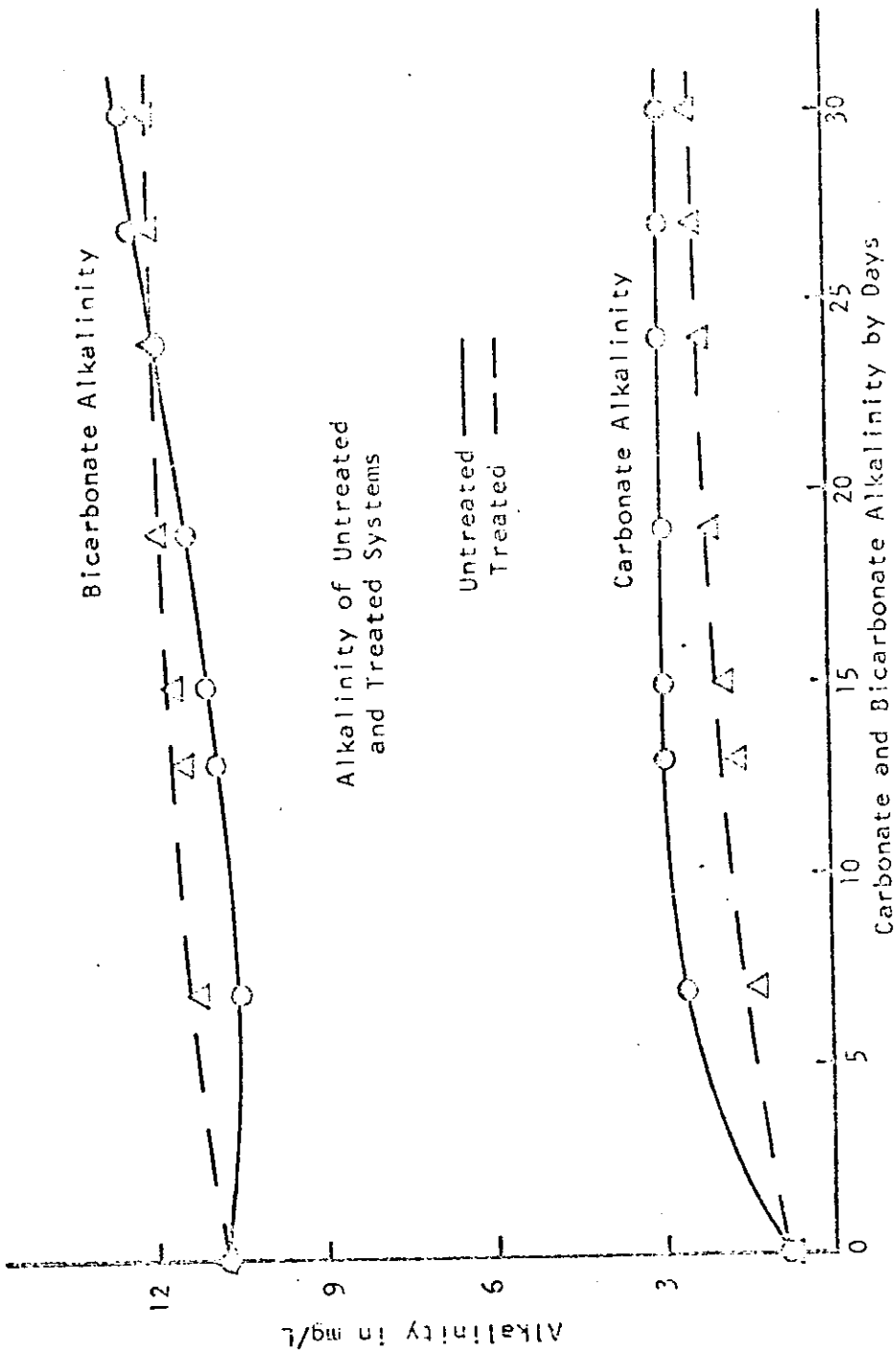

Bicarbonate Alkalinity
Carbonate Alkalinity
Alkalinity of Untreated and Treated Systems
Untreated
Treated
Alkalinity in mg/L
12
9
6
3
0
5
10
15
20
25
30
Carbonate and Bicarbonate Alkalinity by Days

Figure 2

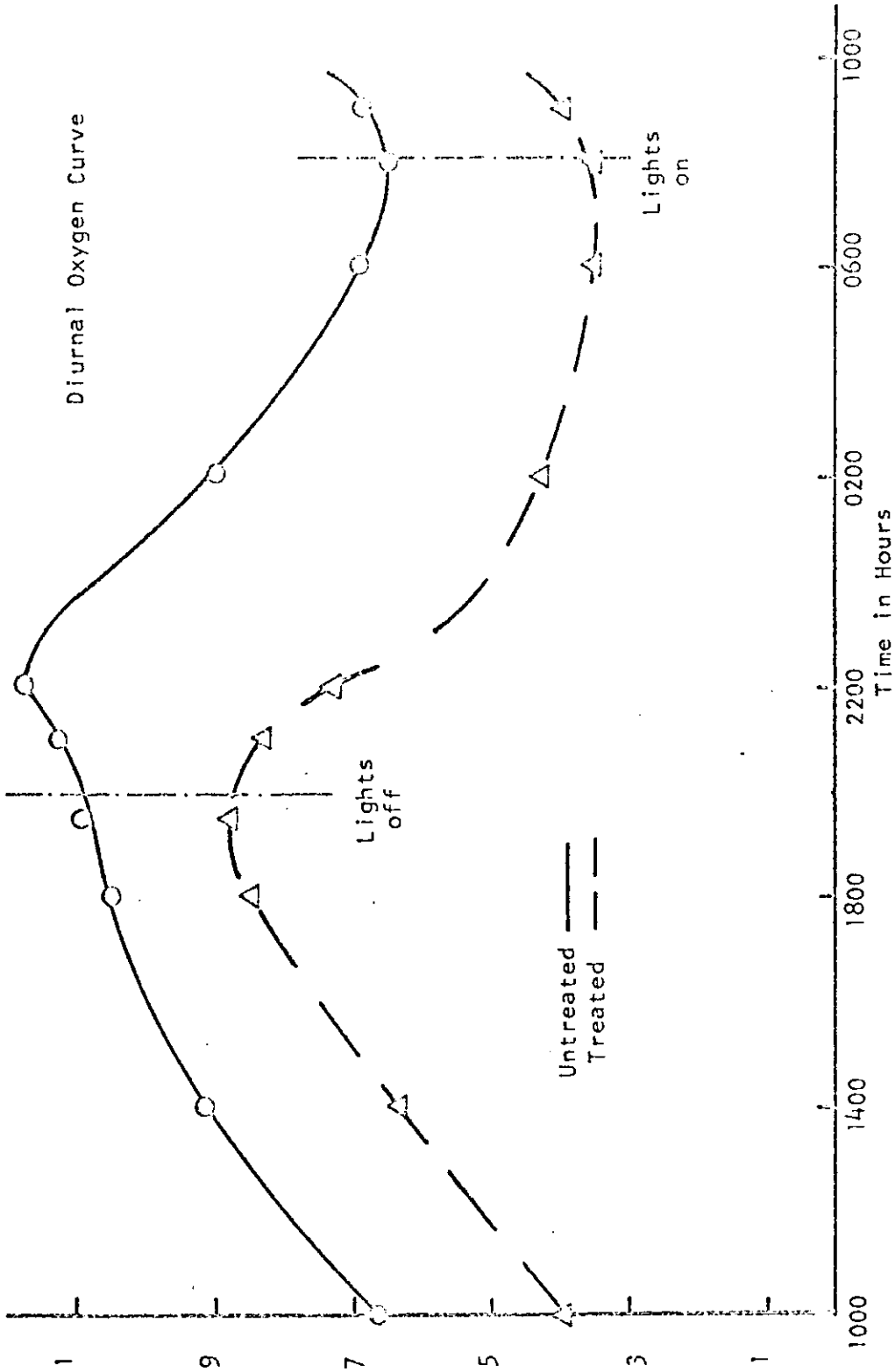

Diurnal Oxygen Curve
Dissolved Oxygen in mg/L
11
9
7
5
3
1
1000
1400
1800
2200
0200
0600
1000
Time in Hours
Lights off
Lights on
Untreated
Treated

Figure 3

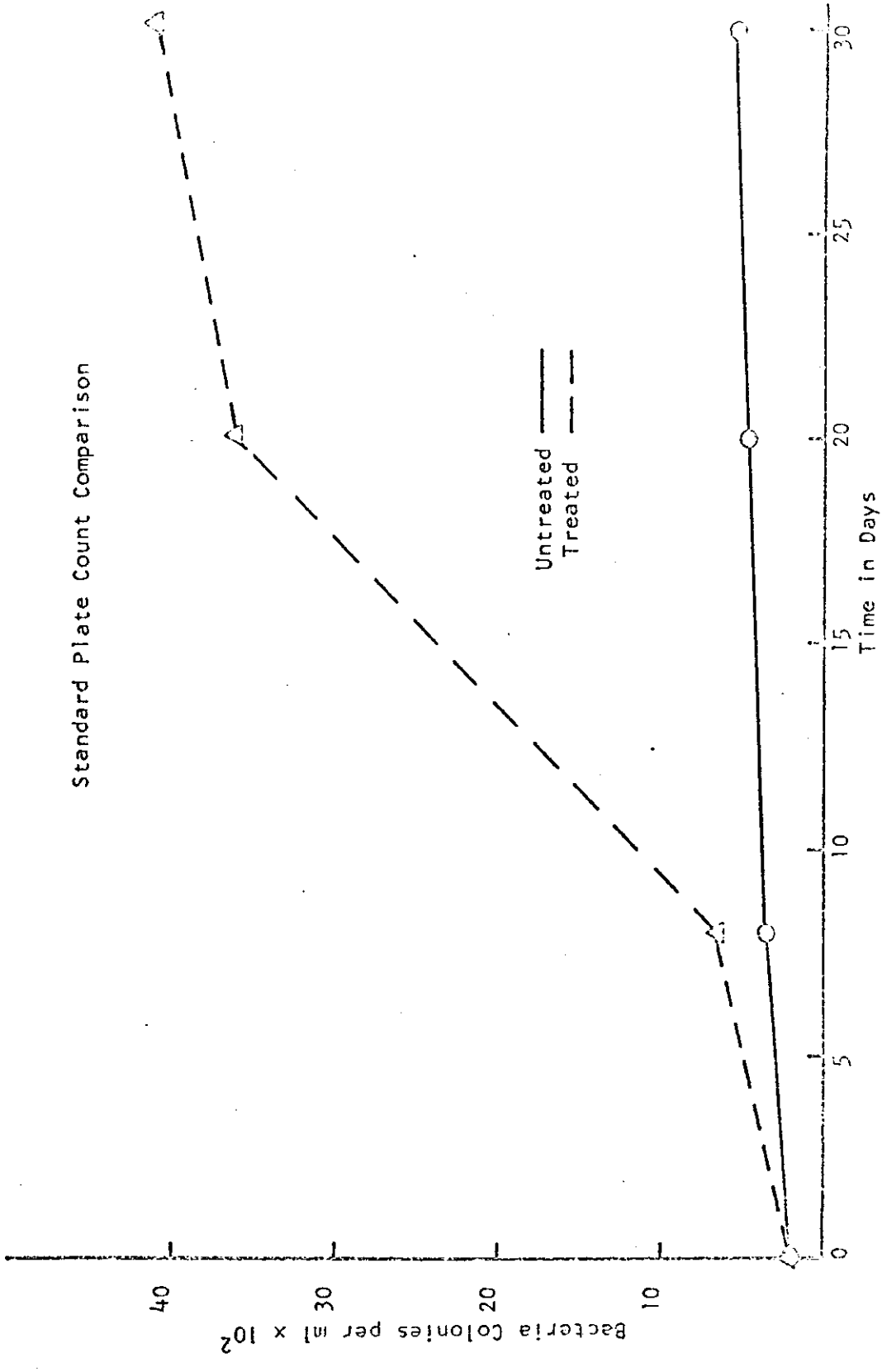

Standard Plate Count Comparison
Untreated
Treated
Time in Days
0
5
10
15
20
25
30
10
20
30
40
Bacteria Colonies per ml x 10²

Figure 4

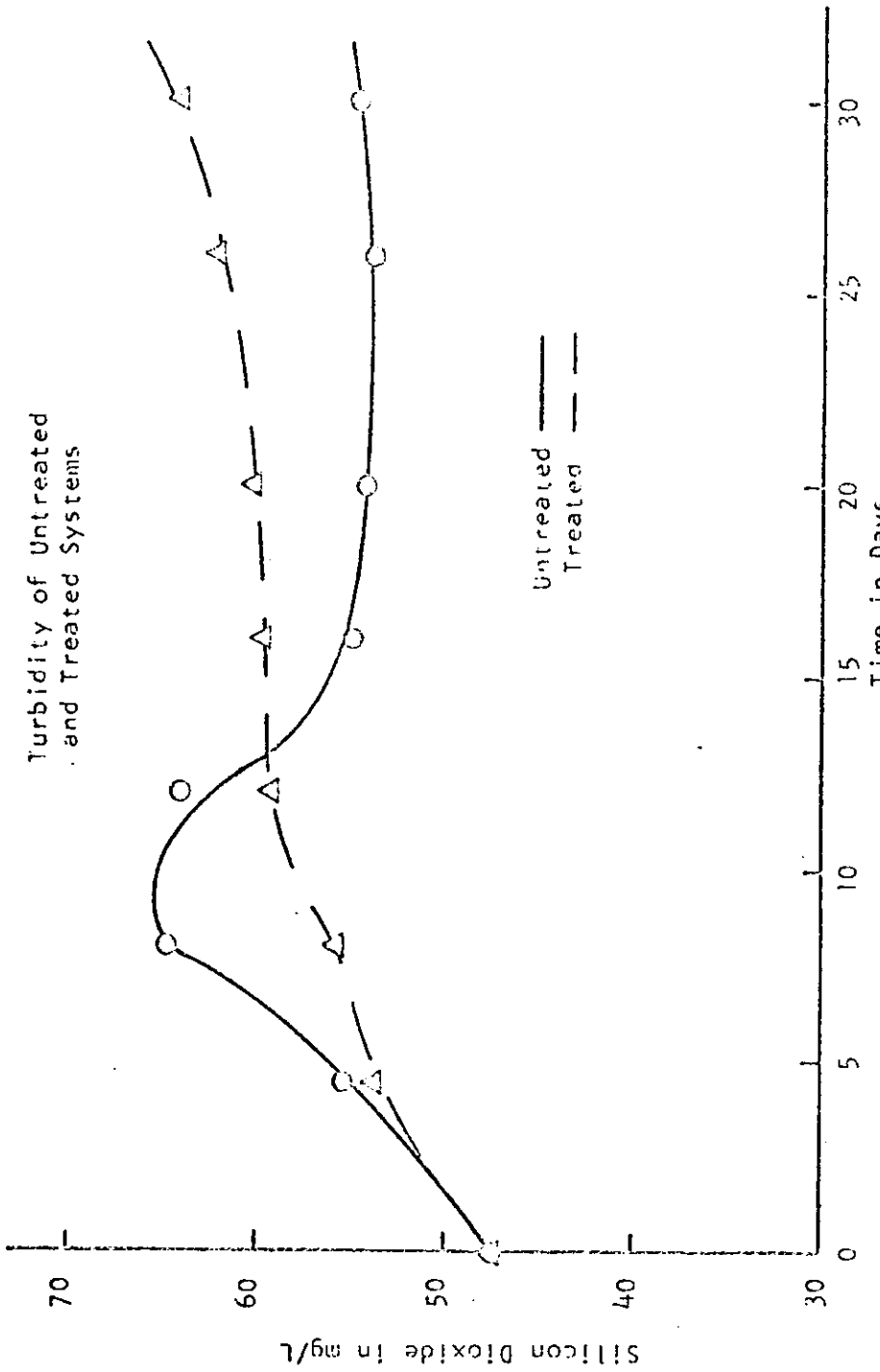

Turbidity of Untreated
and Treated Systems
Untreated
Treated
Silicon Dioxide in mg/L
70
60
50
40
30
0
5
10
15
20
25
30
Time in Days

Figure 5

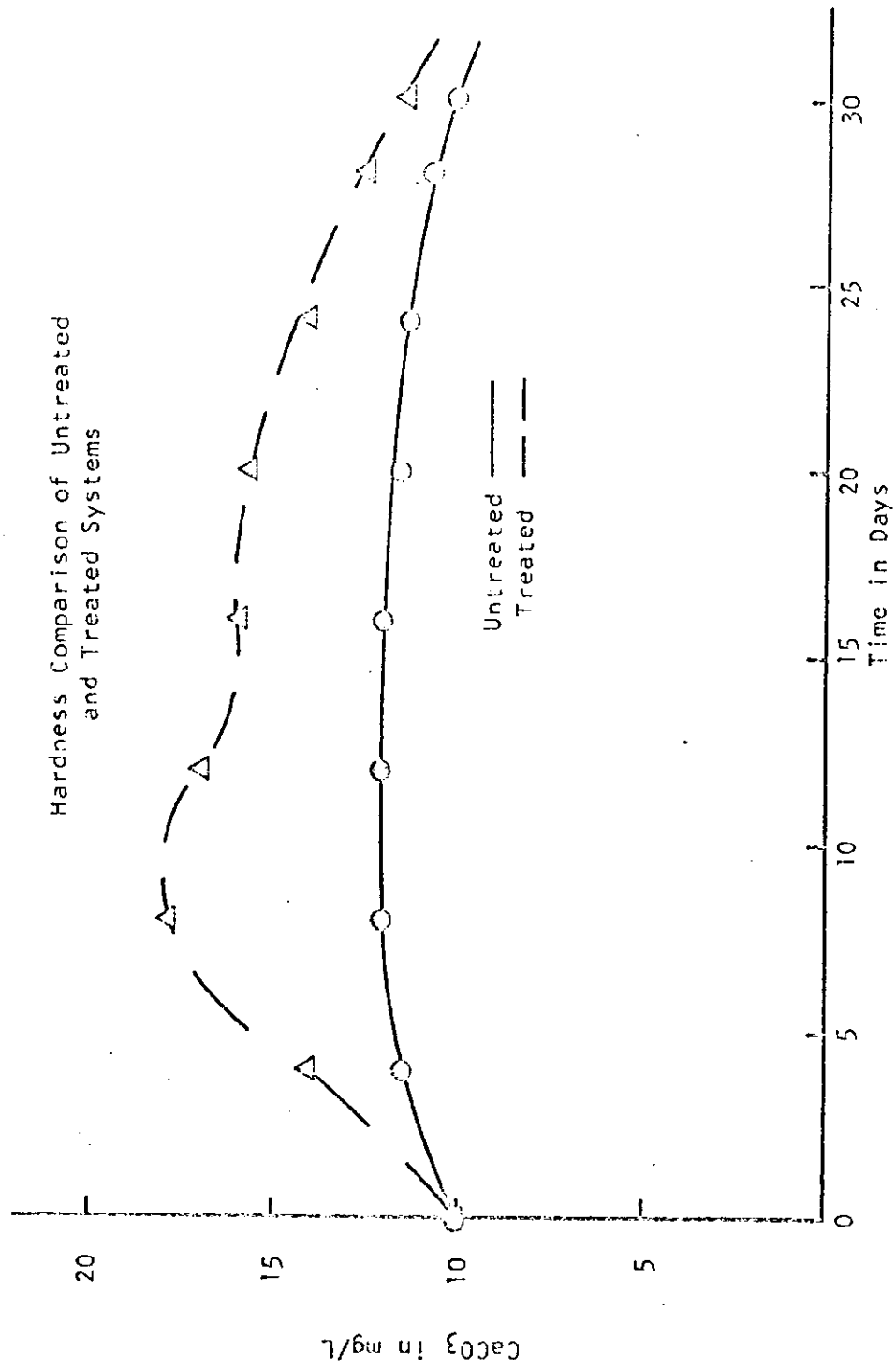

Hardness Comparison of Untreated
and Treated Systems
Untreated
Treated
CaCO3 in mg/L
Time in Days
0
5
10
15
20
25
30

Figure 6

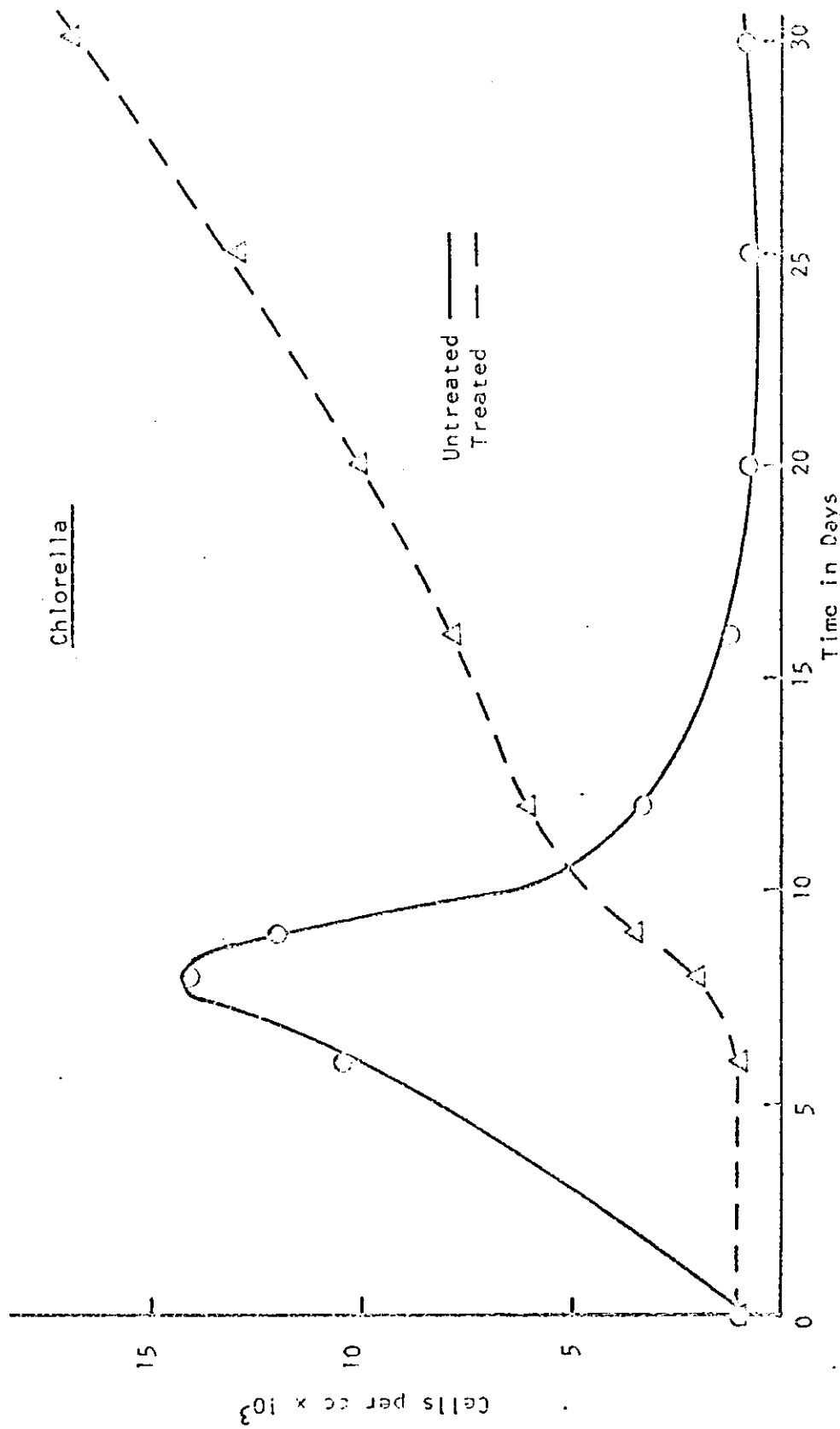

Chlorella
Untreated
Treated
Time in Days
cells per cc x 10^3
0
5
10
15
20
25
30

Figure 7

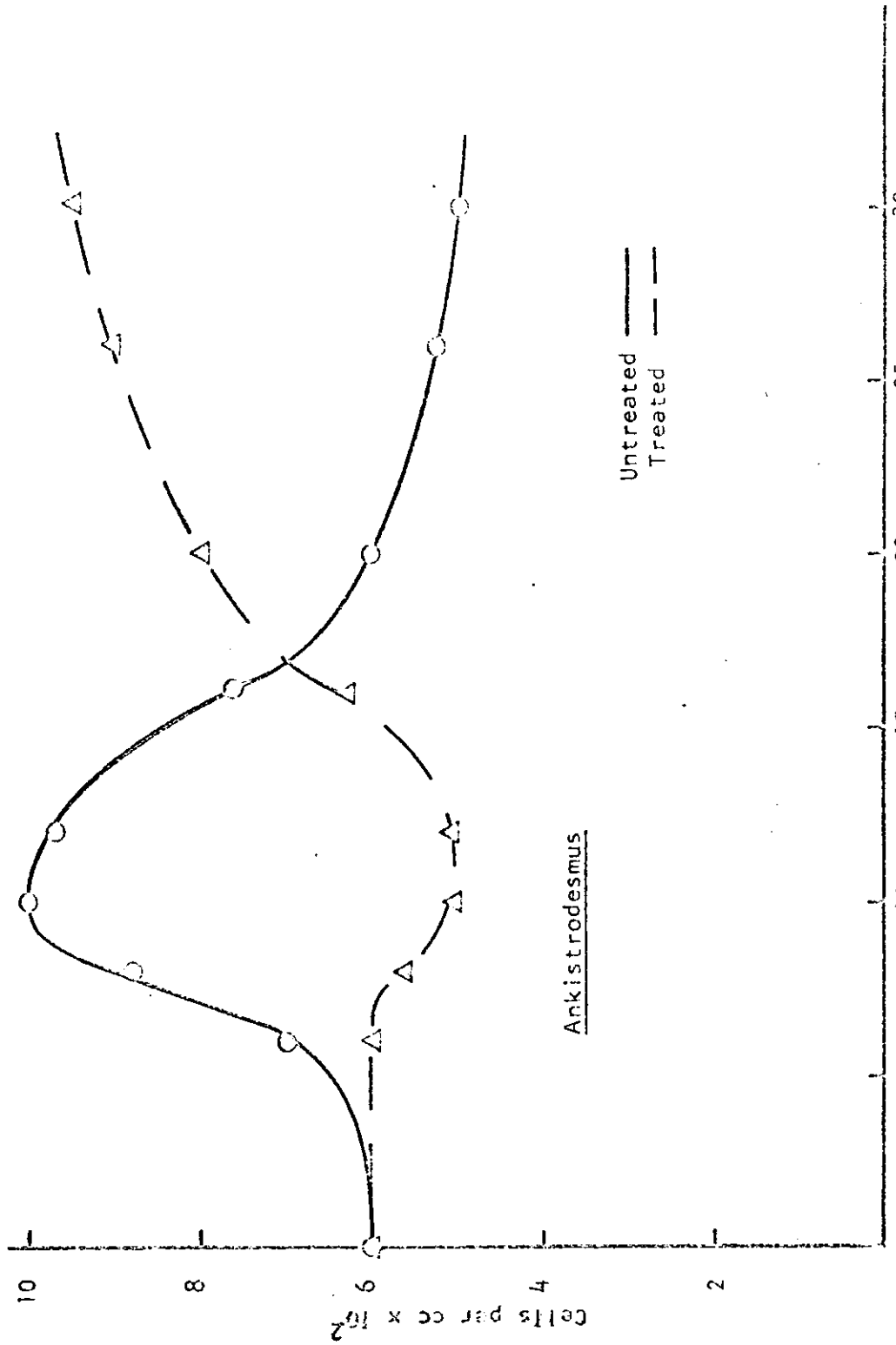

Cells per cc x 10^2
10
8
6
4
2
0
5
10
15
20
25
30
Time in Days
Untreated
Treated
Ankistrodesmus

Figure 8

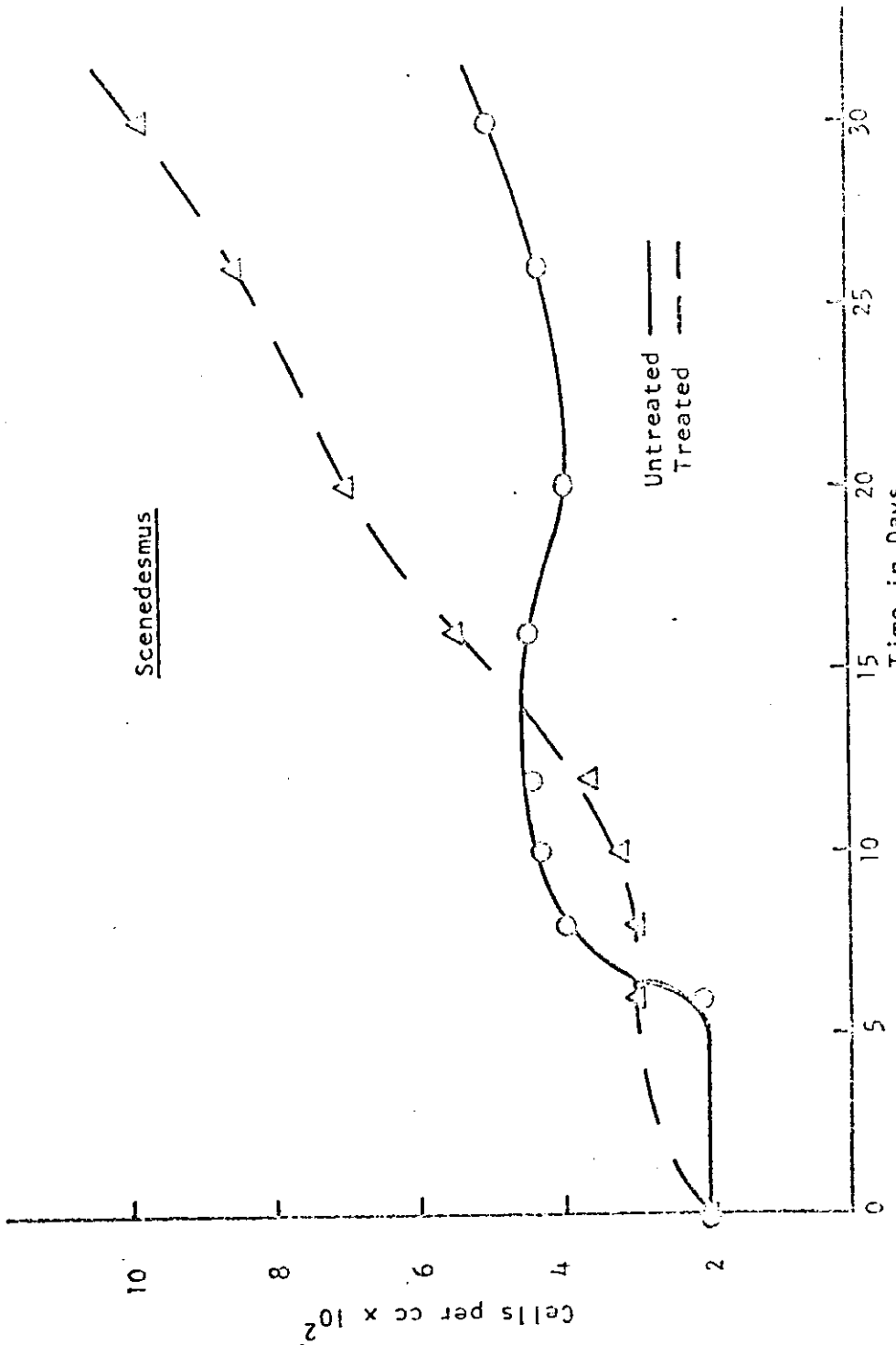

Scenedesmus
Untreated
Treated
Time in Days
Cells per cc x 10^2
0
5
10
15
20
25
30
2
4
6
8
10

Figure 9

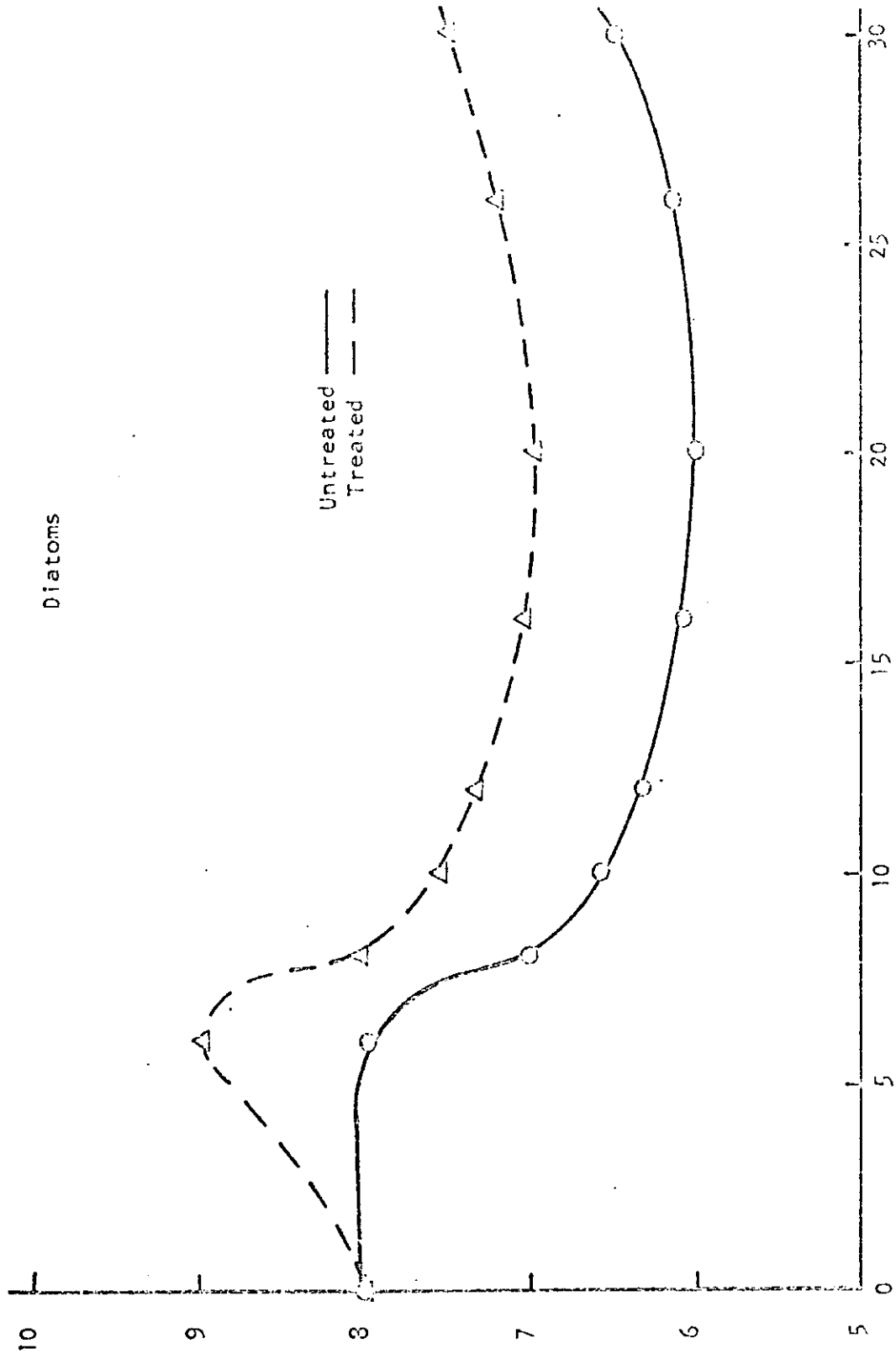

Diatoms
Untreated
Treated
cells per cc x 10³
10
9
8
7
6
5
0
5
10
15
20
25
30
Time in Days

Figure 10

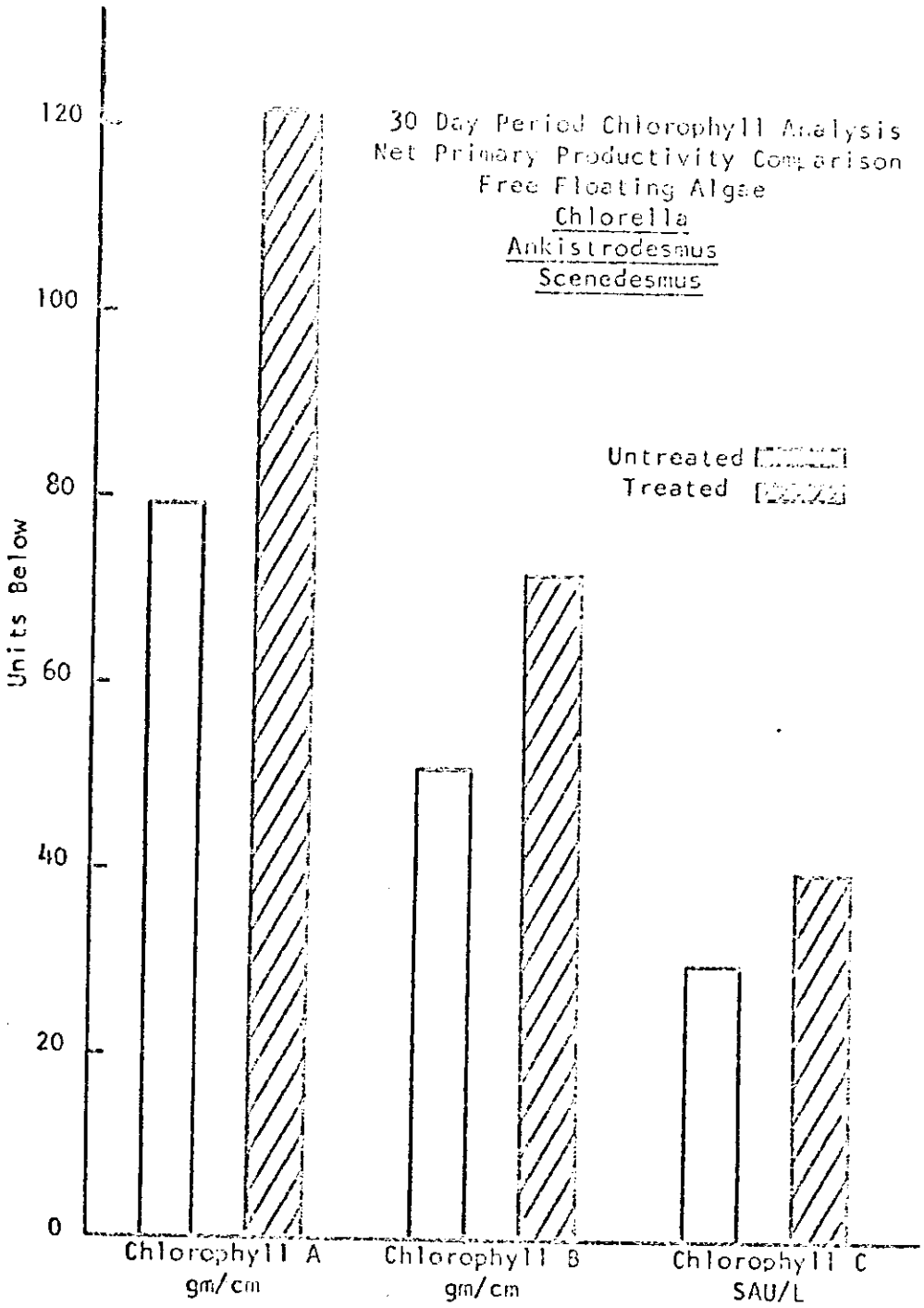
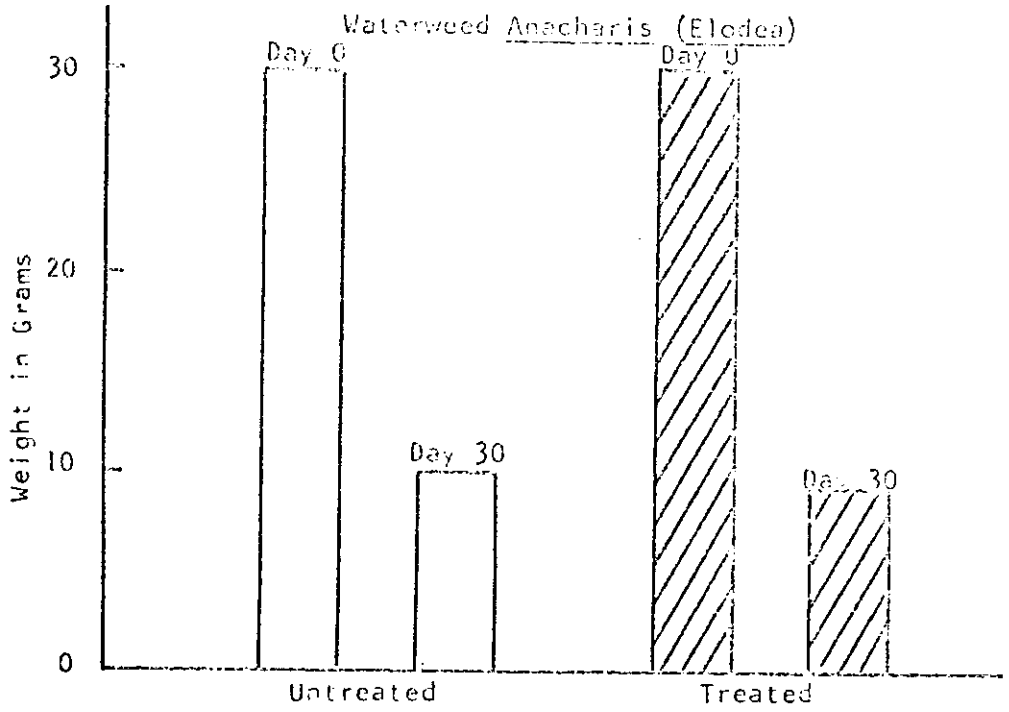

30 Day Period Chlorophyll Analysis
Net Primary Productivity Comparison
Free Floating Algae
Chlorella
Ankistrodesmus
Scenedesmus
Untreated
Treated
Units Below
120
100
80
60
40
20
0
Chlorophyll A
gm/cm
Chlorophyll B
gm/cm
Chlorophyll C
SAU/L

Figure 11



Biomass Comparison
Net Primary Productivity
Harvest Method

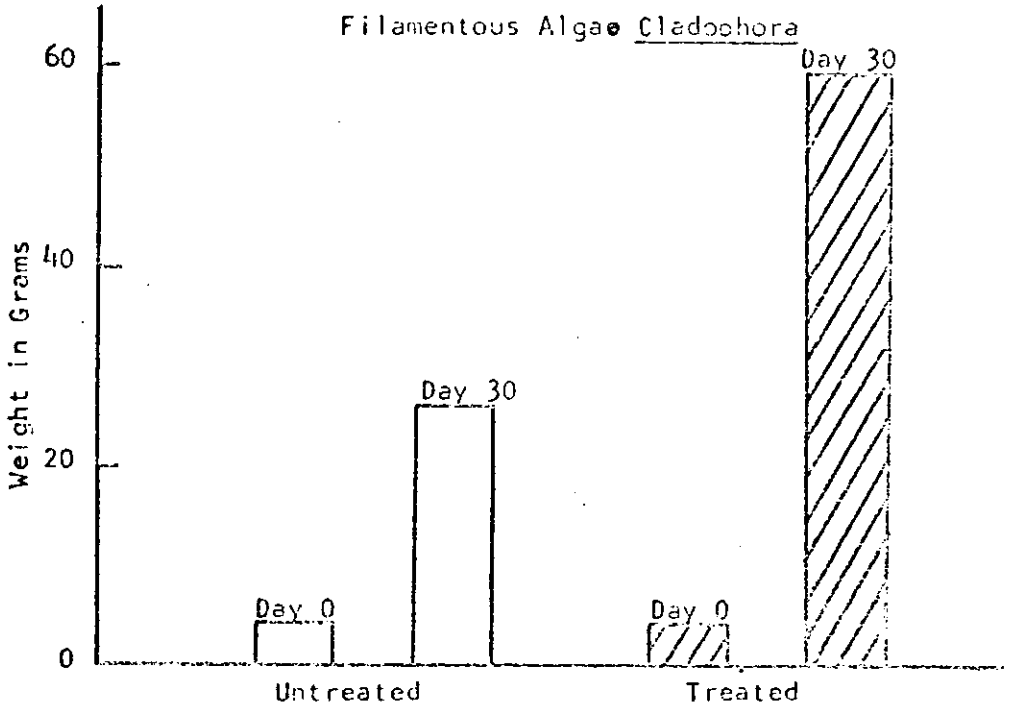


Figure 12

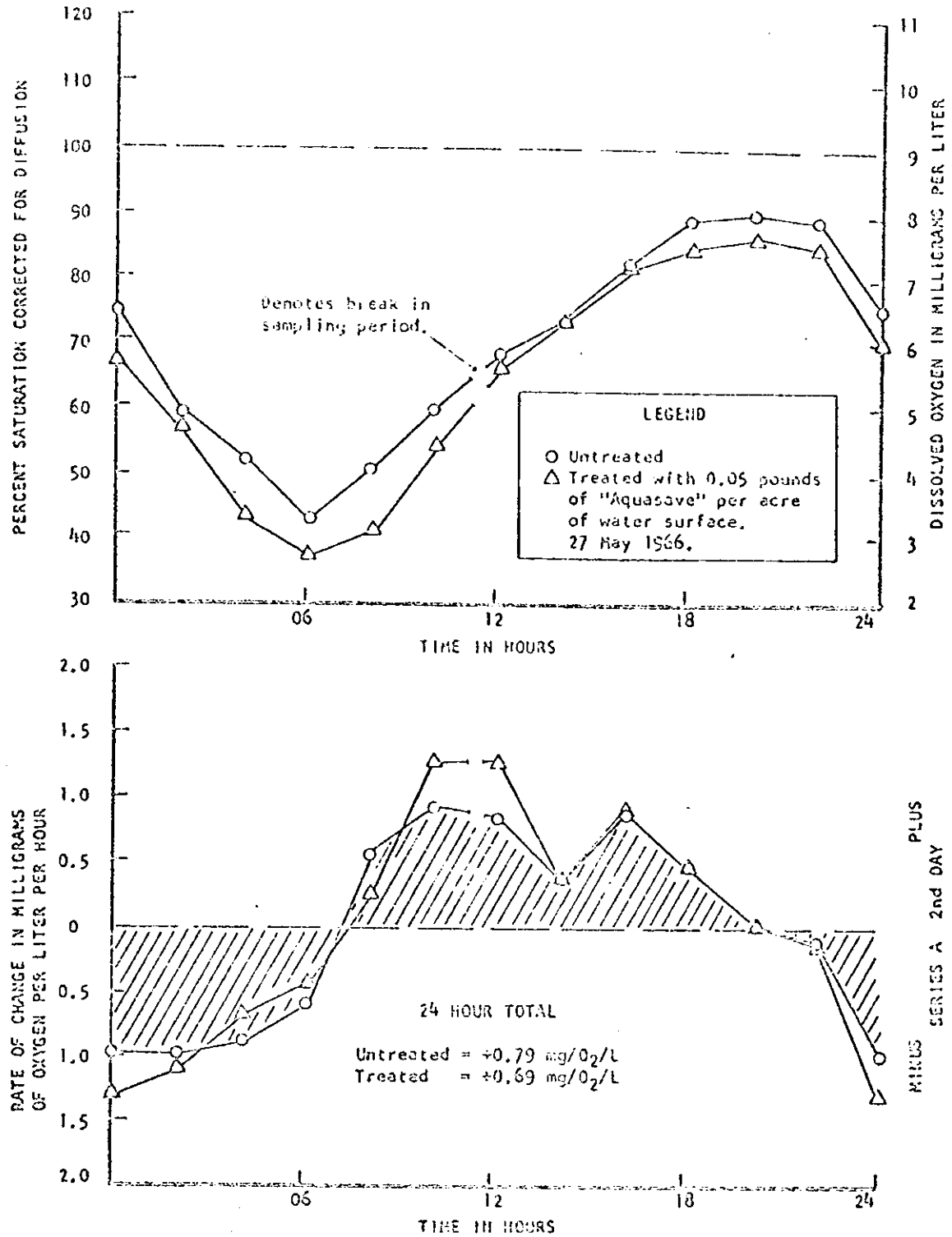


FIGURE 13 A COMPARISON OF DIURNAL OXYGEN AND PRIMARY PRODUCTIVITY IN UNTREATED AND TREATED MICROCOSMS. EXPERIMENT A, 2 DAYS DURATION.

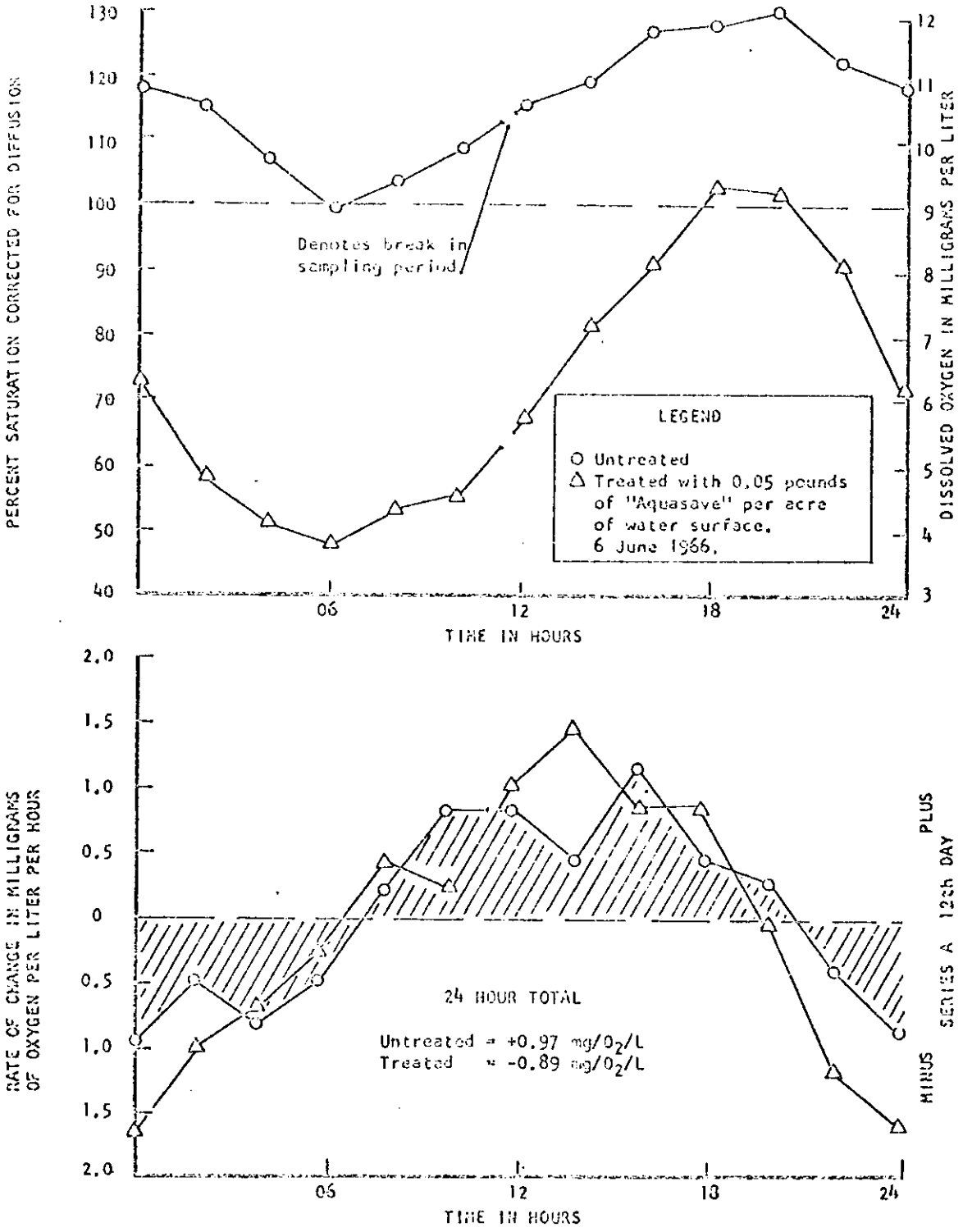


FIGURE 14 A COMPARISON OF DIURNAL OXYGEN AND PRIMARY PRODUCTIVITY IN UNTREATED AND TREATED MICROCOSMS. EXPERIMENT A, 12 DAYS DURATION.

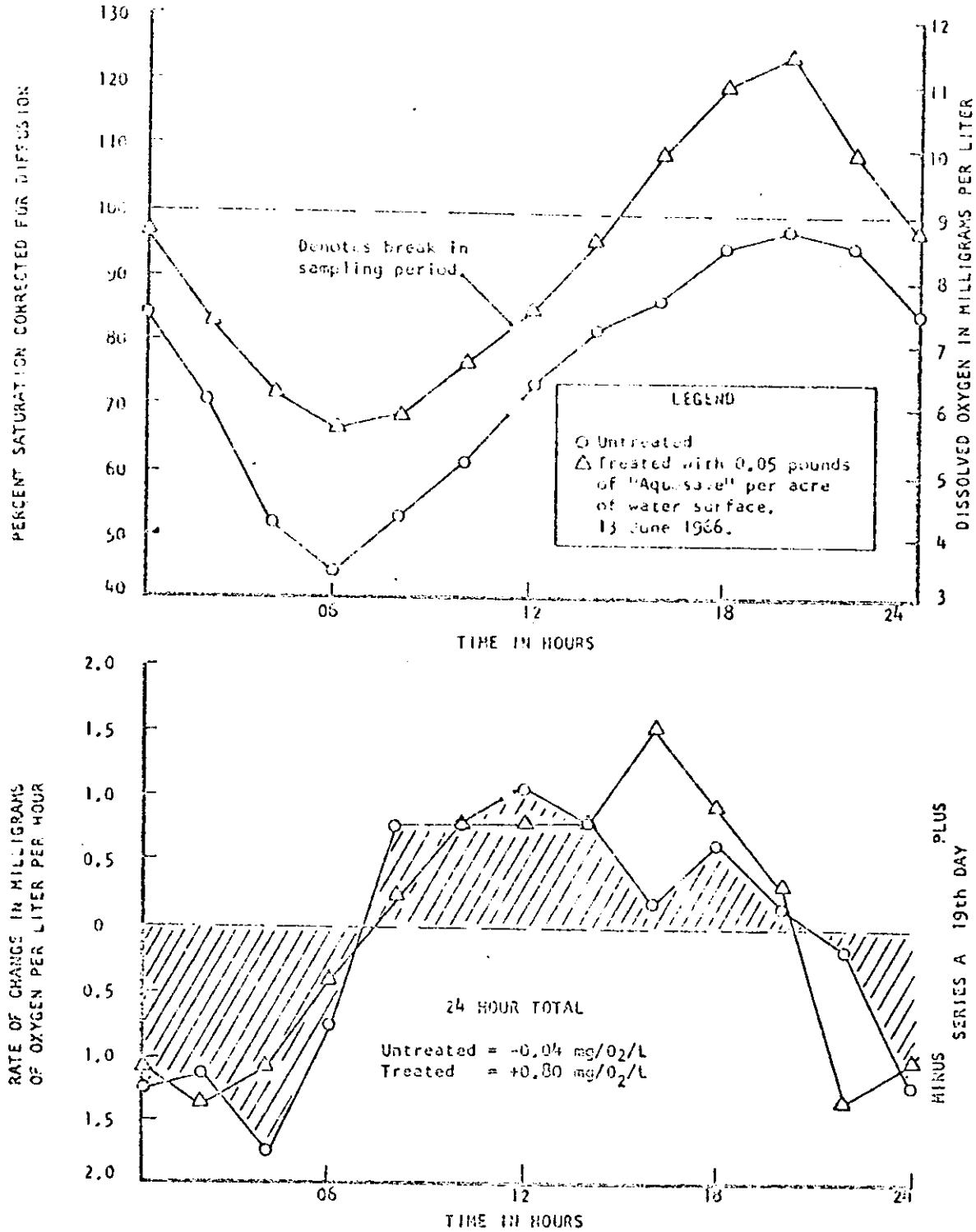


FIGURE 15 A COMPARISON OF DIURNAL OXYGEN AND PRIMARY PRODUCTIVITY IN UNTREATED AND TREATED MICROCOSMS. EXPERIMENT A, 19 DAYS DURATION.

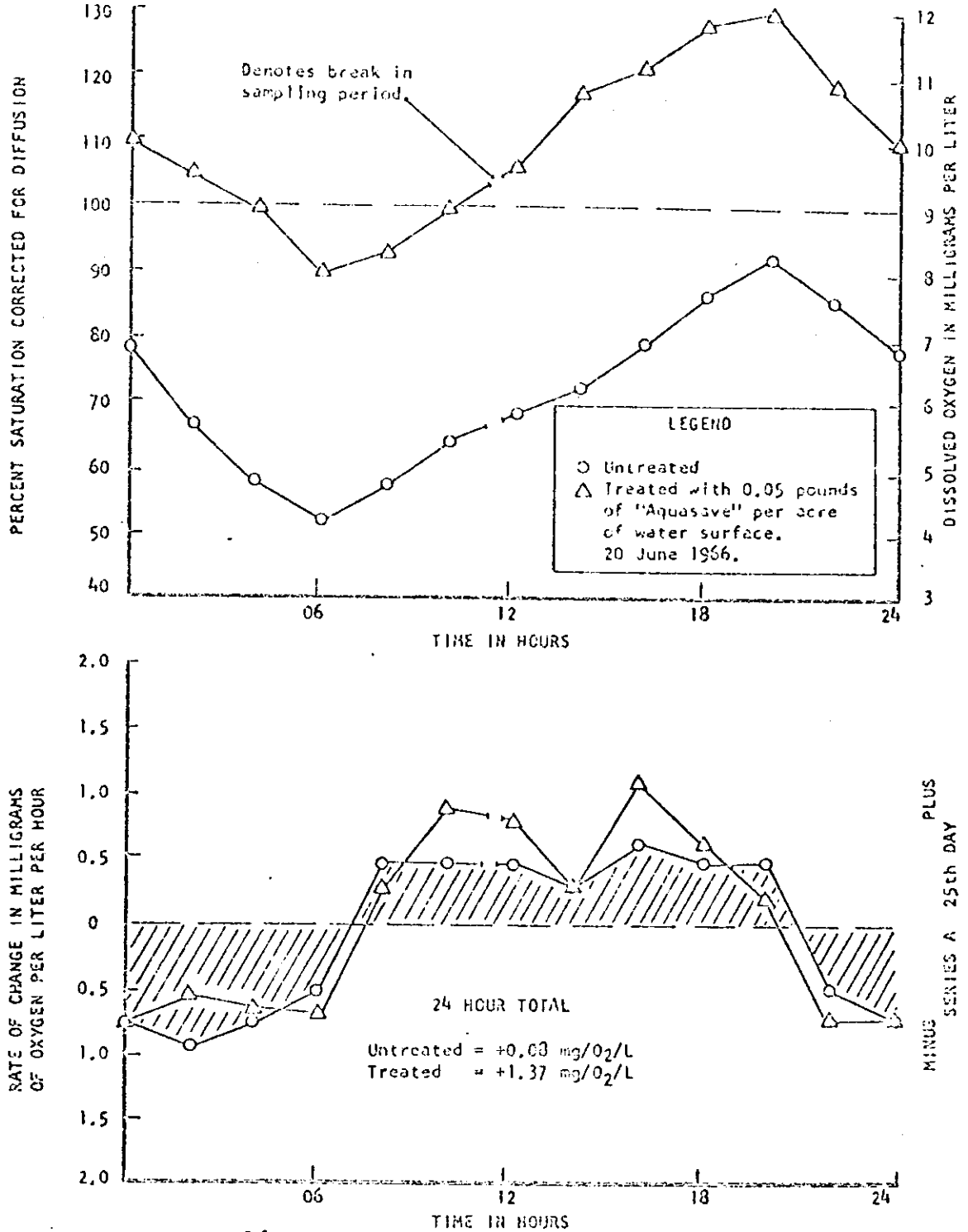


FIGURE 16 A COMPARISON OF DIURNAL OXYGEN AND PRIMARY PRODUCTIVITY IN UNTREATED AND TREATED MICROCOSMS. EXPERIMENT A, 25 DAYS DURATION.

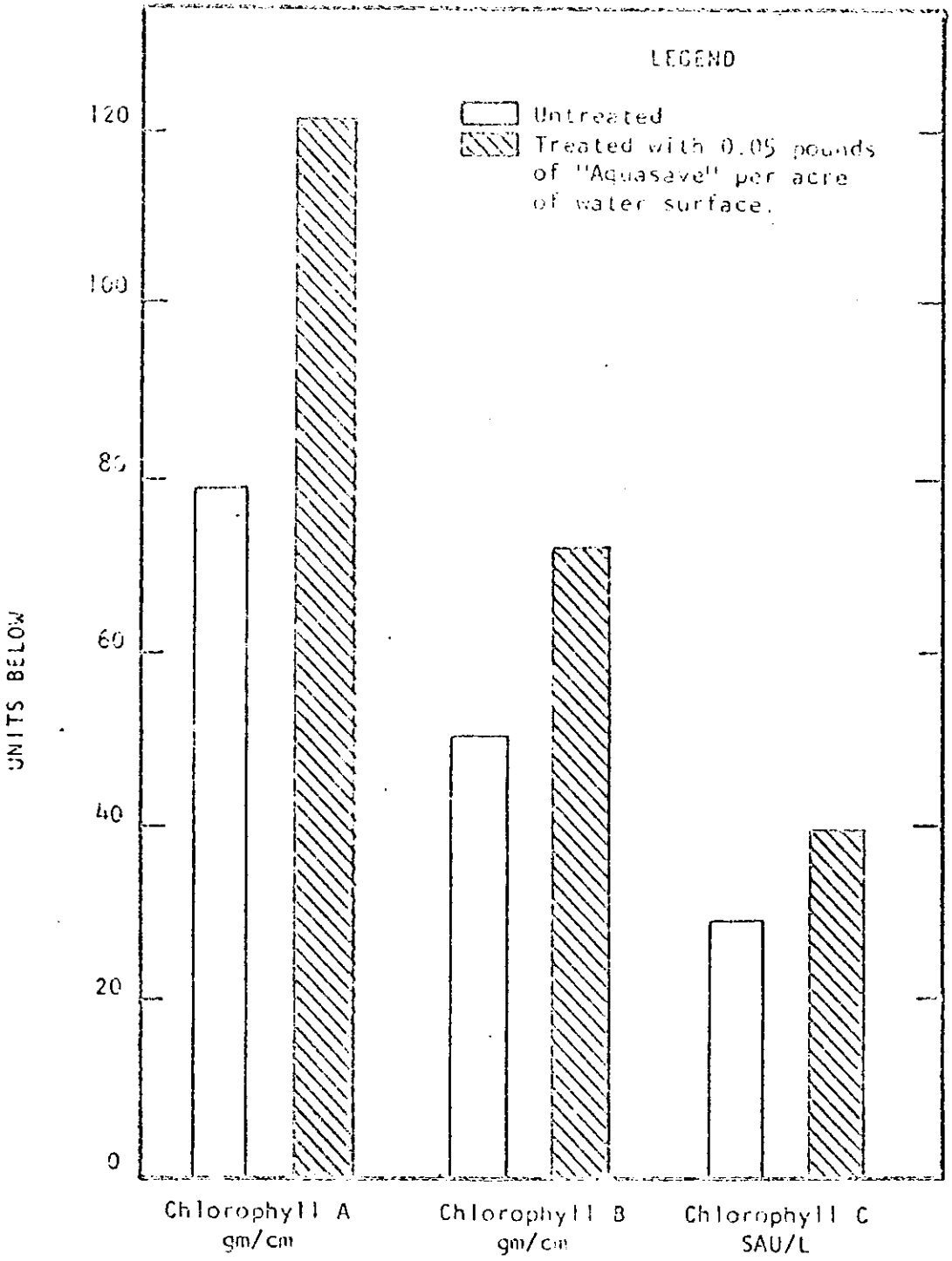


FIGURE 17 A CHLOROPHYLL ANALYSIS COMPARING NET PRIMARY PRODUCTIVITY IN UNTREATED AND TREATED AQUATIC EXPERIMENTAL ECOSYSTEMS ON 24 JUNE 1966. EXPERIMENT A

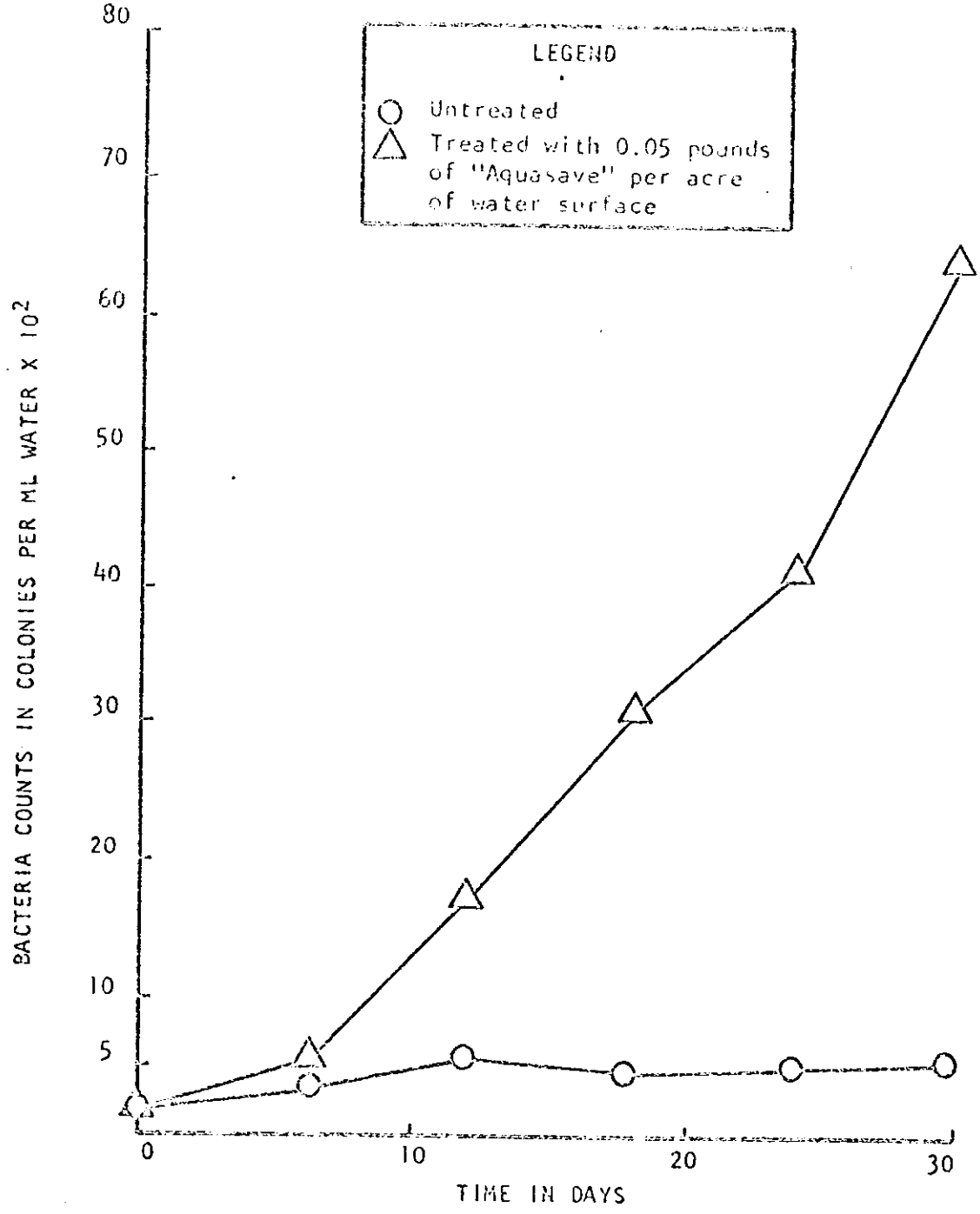


FIGURE 18 A COMPARISON OF BACTERIA COLONIES PER ML OF WATER IN UNTREATED AND TREATED AQUATIC EXPERIMENTAL ECOSYSTEMS FROM 26 MAY to 24 JUNE 1966. EXPERIMENT A

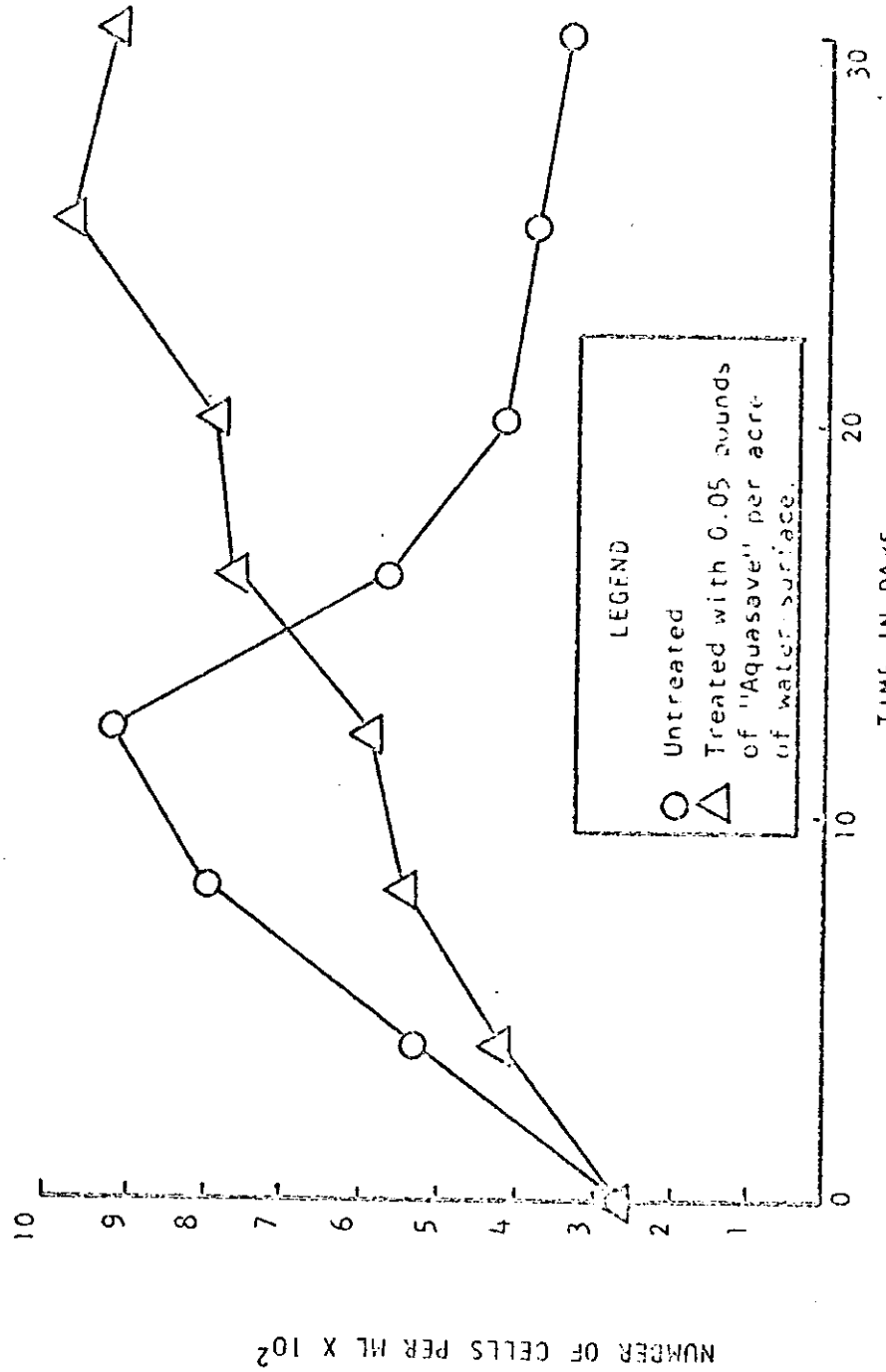


FIGURE 19. CHLORELLA CELL COUNTS IN UNTREATED AND TREATED AQUATIC EXPERIMENTAL ECOSYSTEMS FROM 26 MAY TO 24 JUNE 1966. EXPERIMENT A

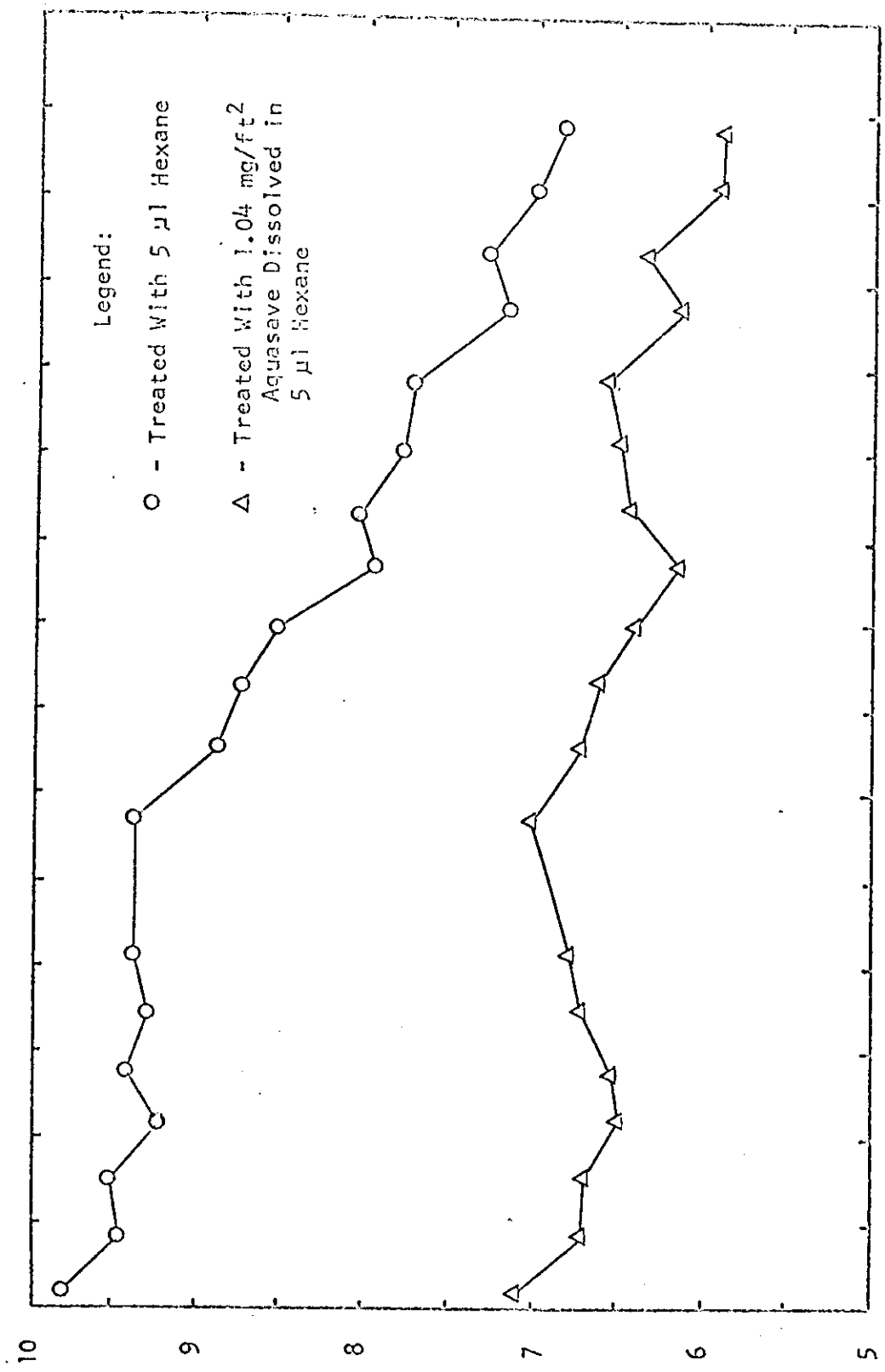


FIGURE 20 EFFECT OF AQUASAVE MONOLAYER ON OXYGEN UPTAKE RATE

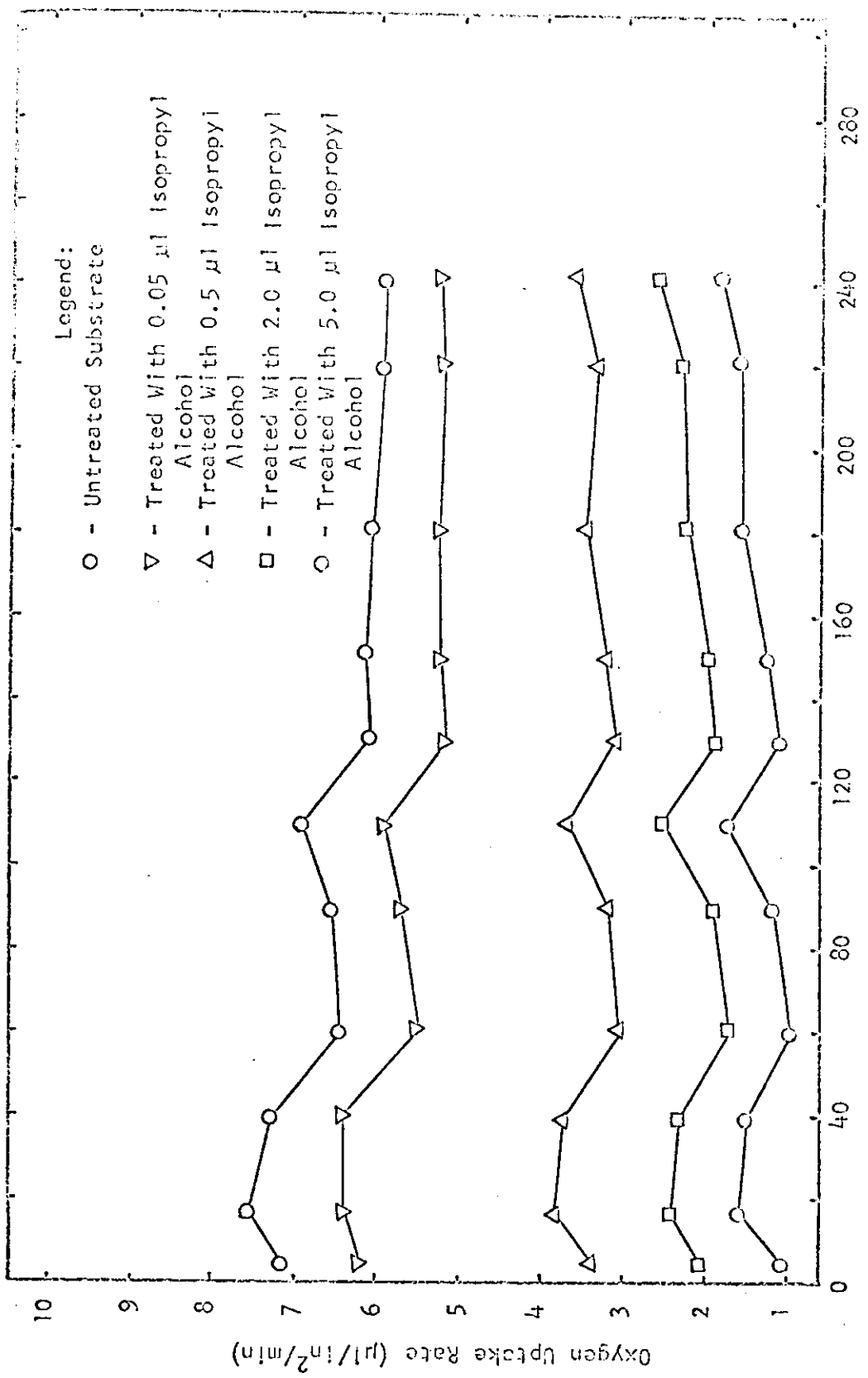


FIGURE 21 EFFECT OF ISOPROPYL ALCOHOL ON OXYGEN UPTAKE RATE

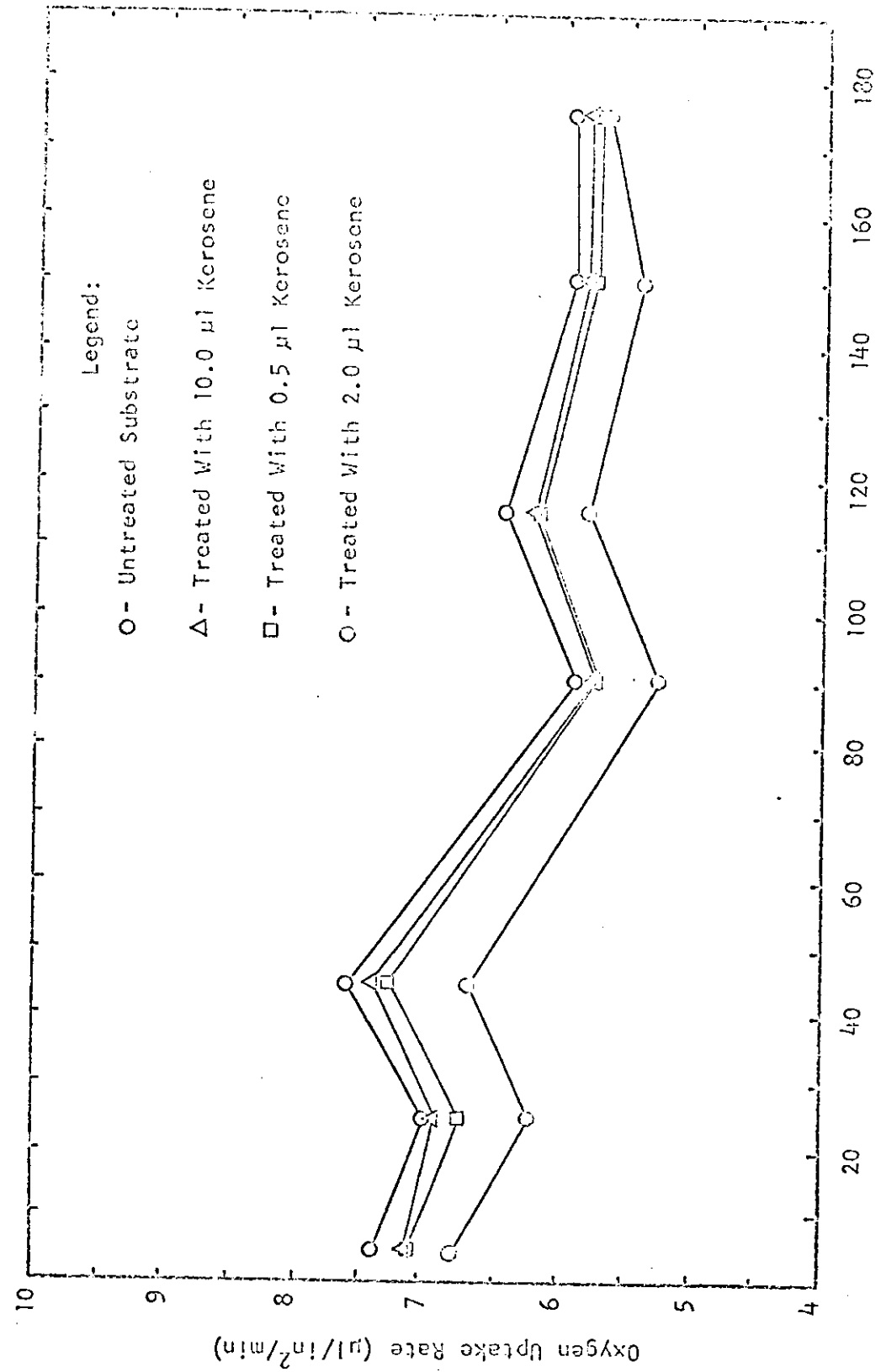


FIGURE 22. EFFECT OF KEROSENE ON OXYGEN UPTAKE RATE

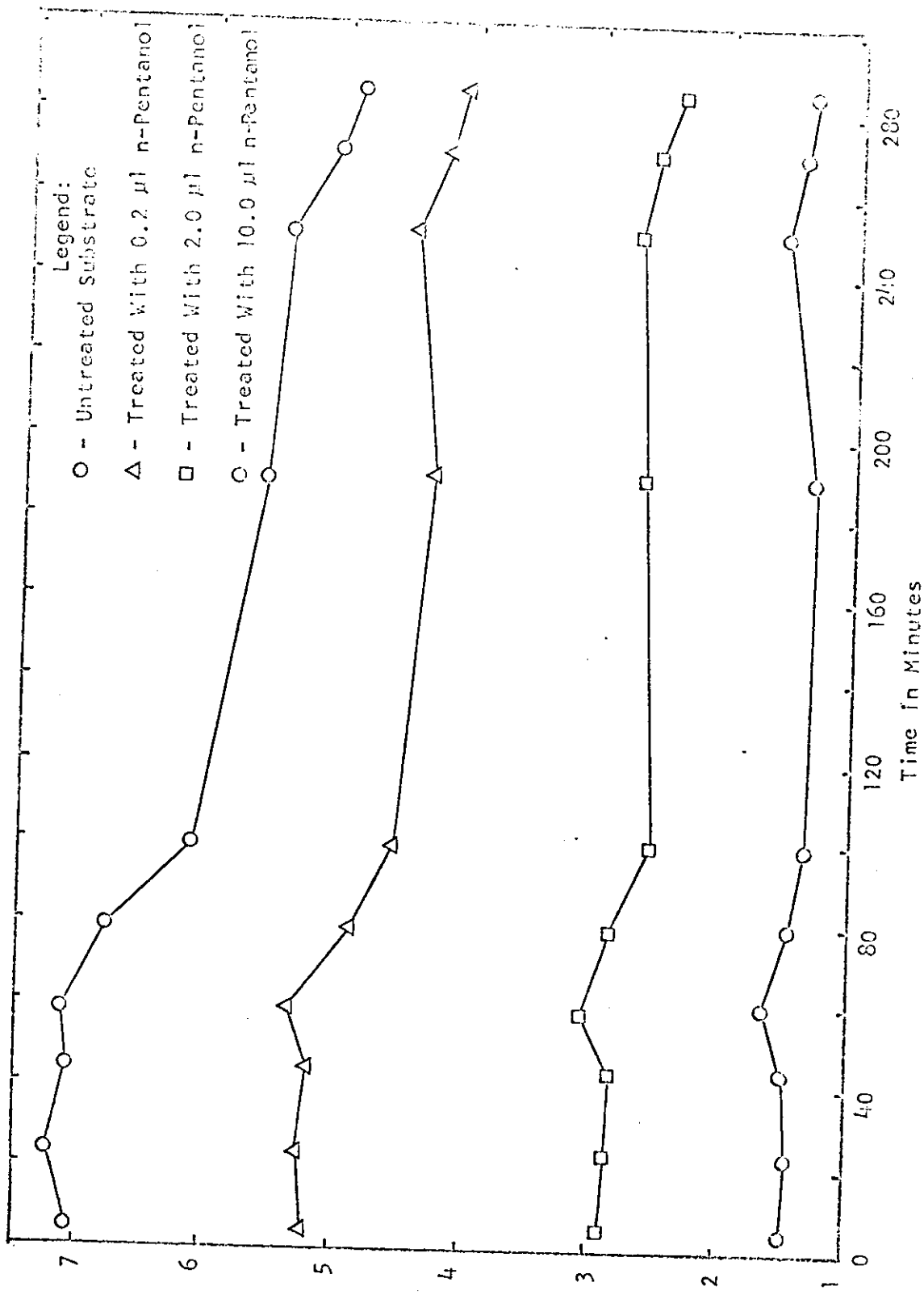


FIGURE 23. EFFECT OF N-PENTANOL ON OXYGEN UPTAKE RATE

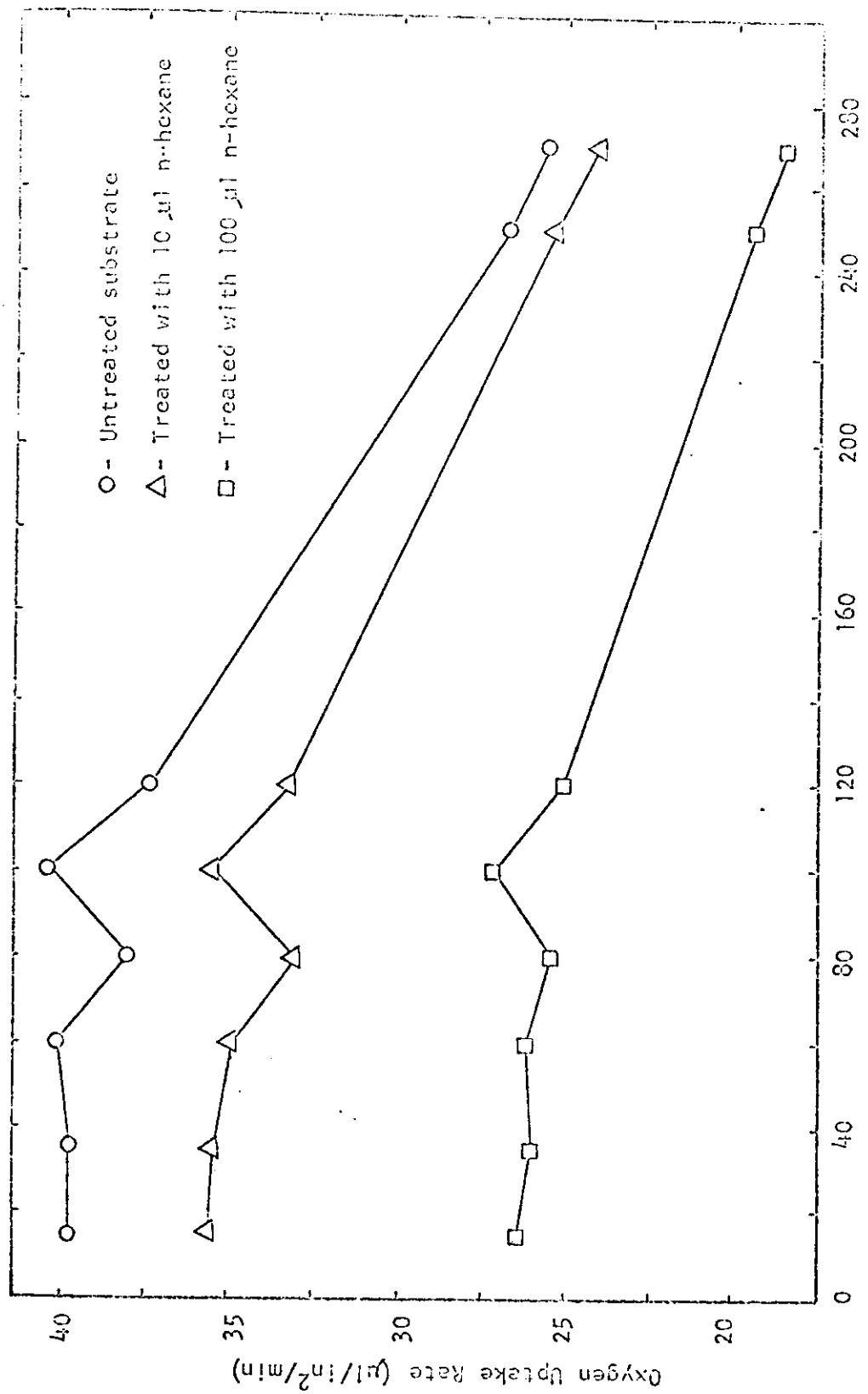


FIGURE 24 EFFECT OF HEXANE ON OXYGEN UPTAKE RATE

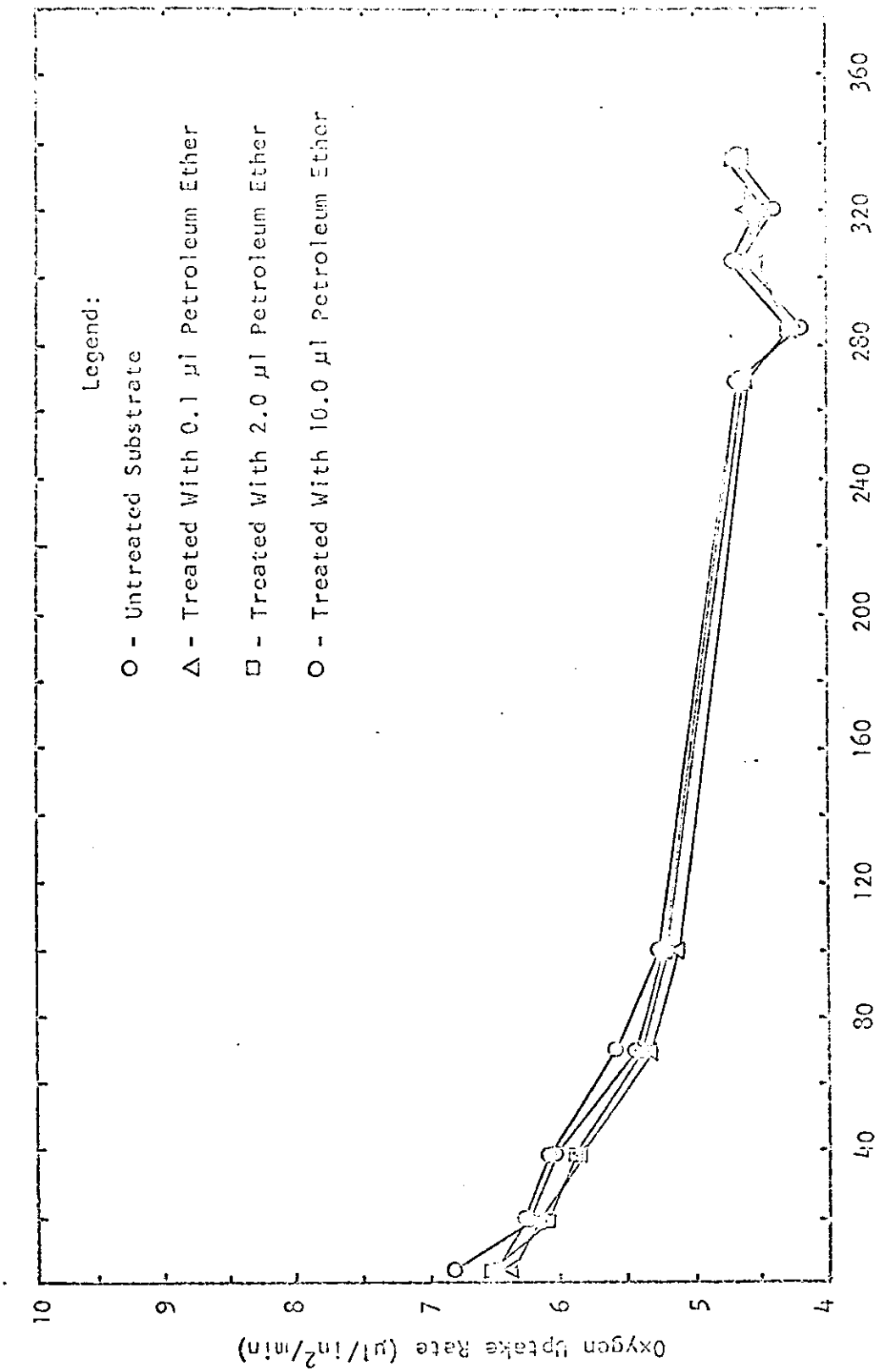


FIGURE 25. EFFECT OF PETROLEUM ETHER ON OXYGEN UPTAKE RATE

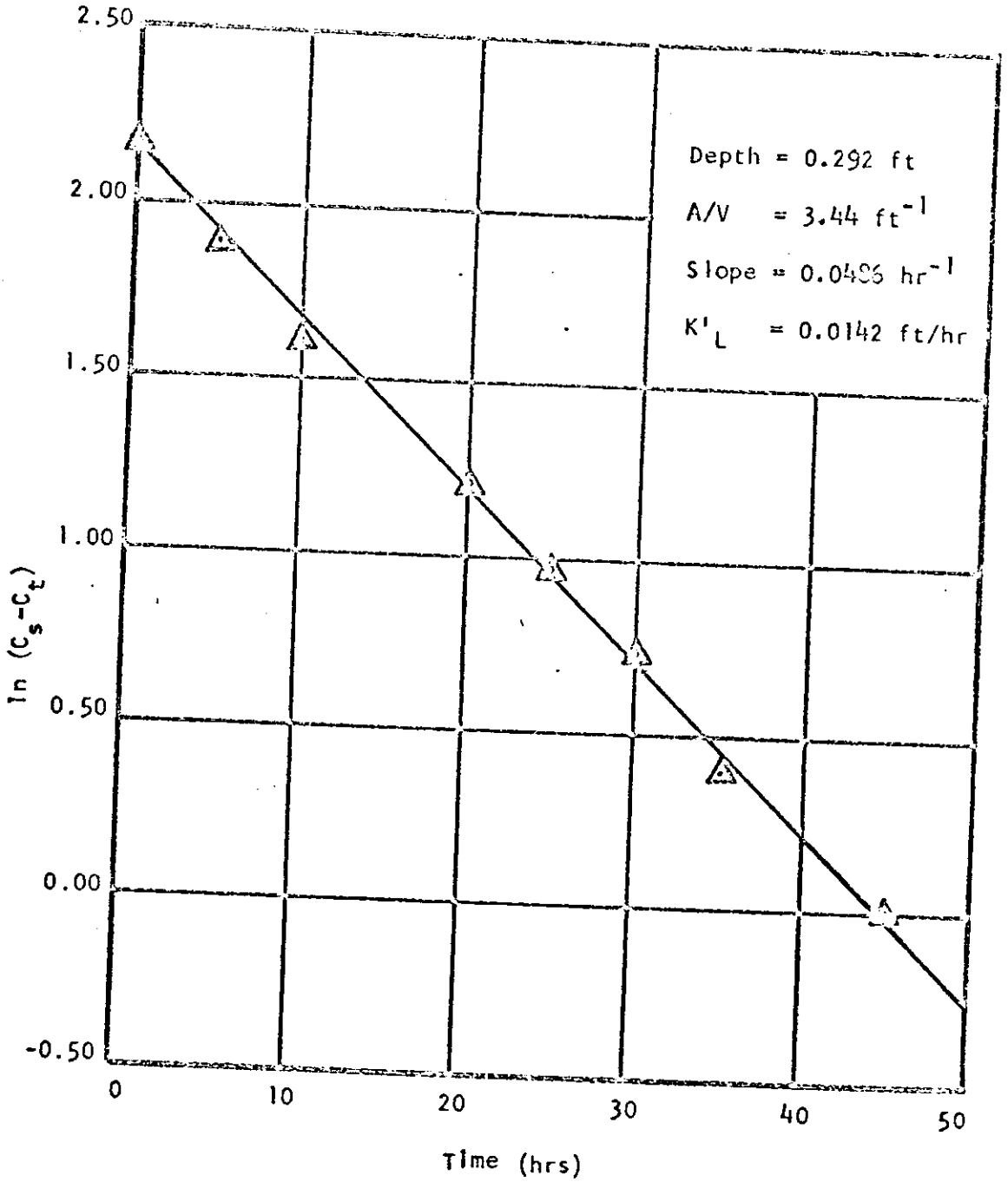


Fig. 26 OXYGEN TRANSFER COEFFICIENT AT 21°C USING DISTILLED WATER WITH "AQUASAVE" - BY D.O. METER

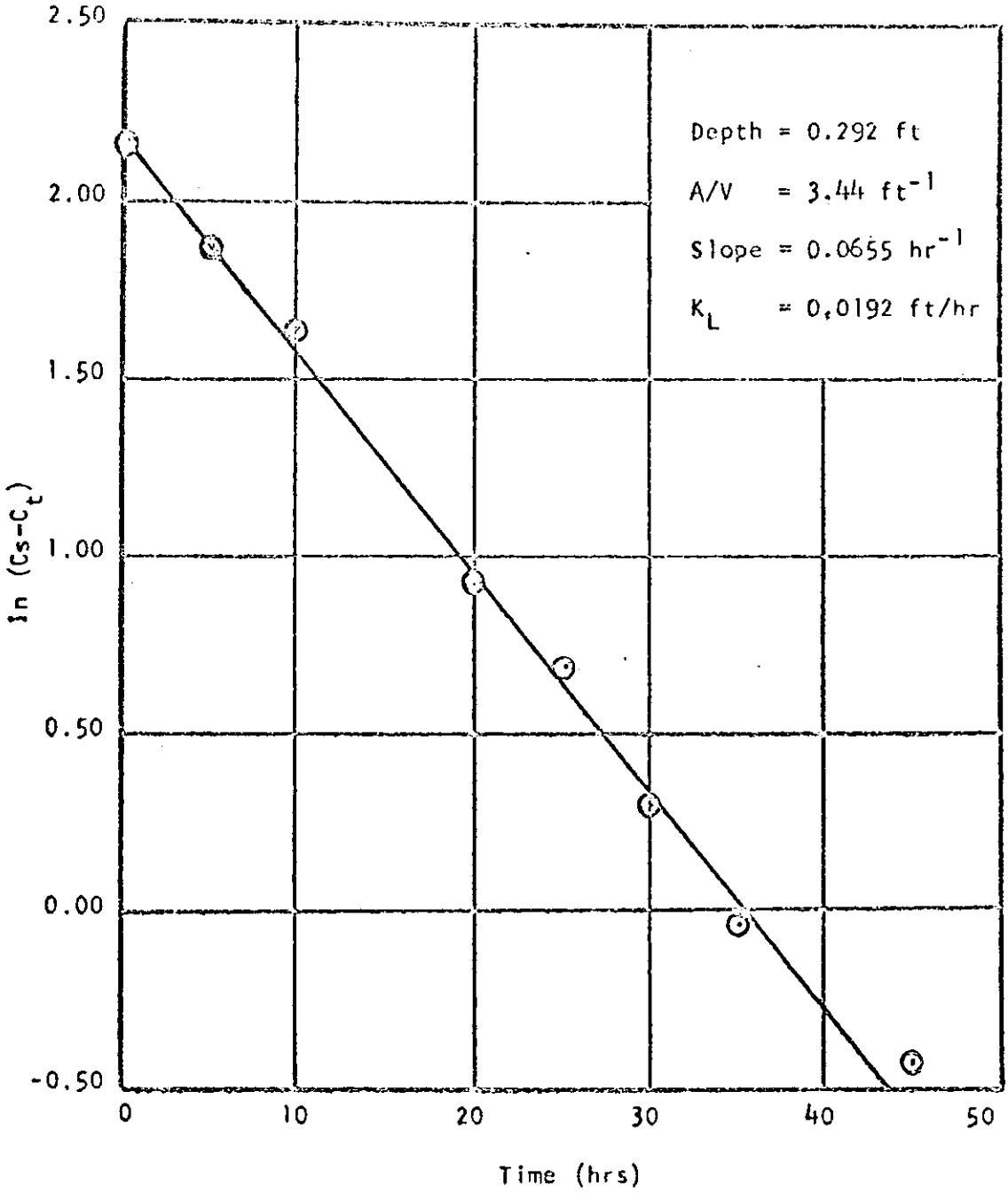


Fig. 27 OXYGEN TRANSFER COEFFICIENT AT 21°C USING DISTILLED WATER WITHOUT "AQUASAVE" - BY D.O.METER.

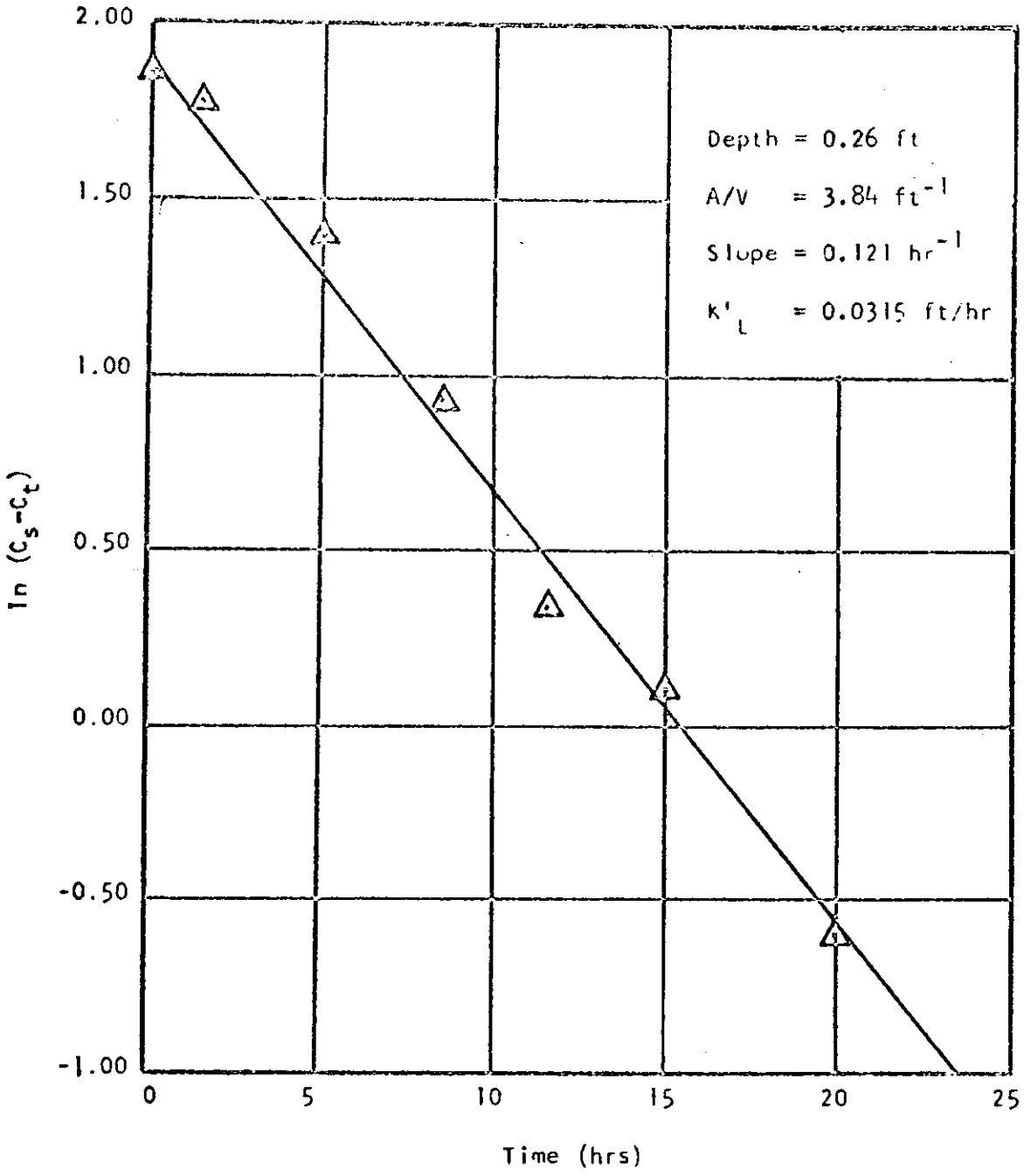


Fig. 28 OXYGEN TRANSFER COEFFICIENT AT 36°C USING DISTILLED WATER WITH "AQUASAVE" - BY D.O. METER

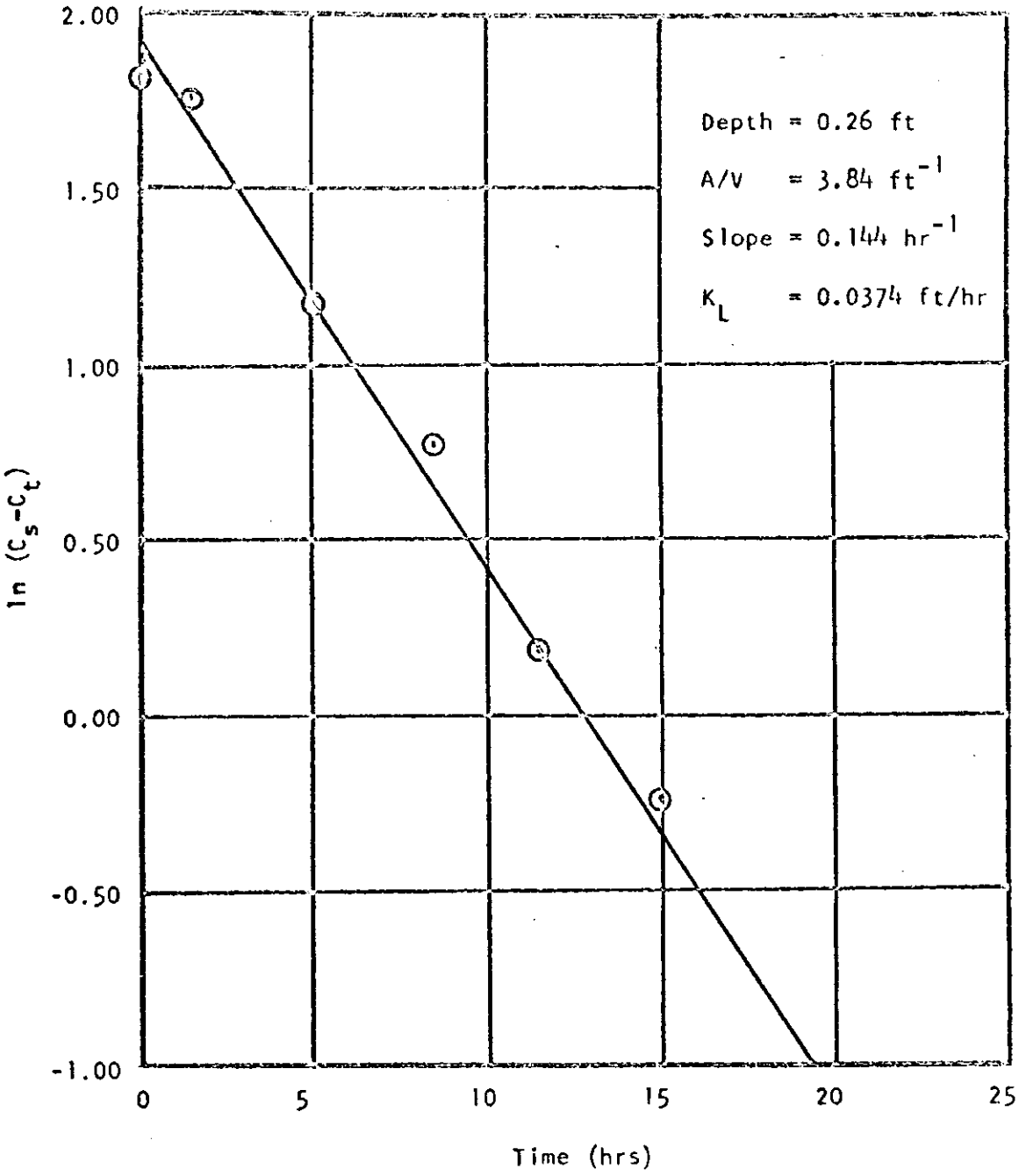


Fig. 29 OXYGEN TRANSFER COEFFICIENT AT 36°C USING DISTILLED WATER WITHOUT "AQUASAVE" - BY D.O. METER

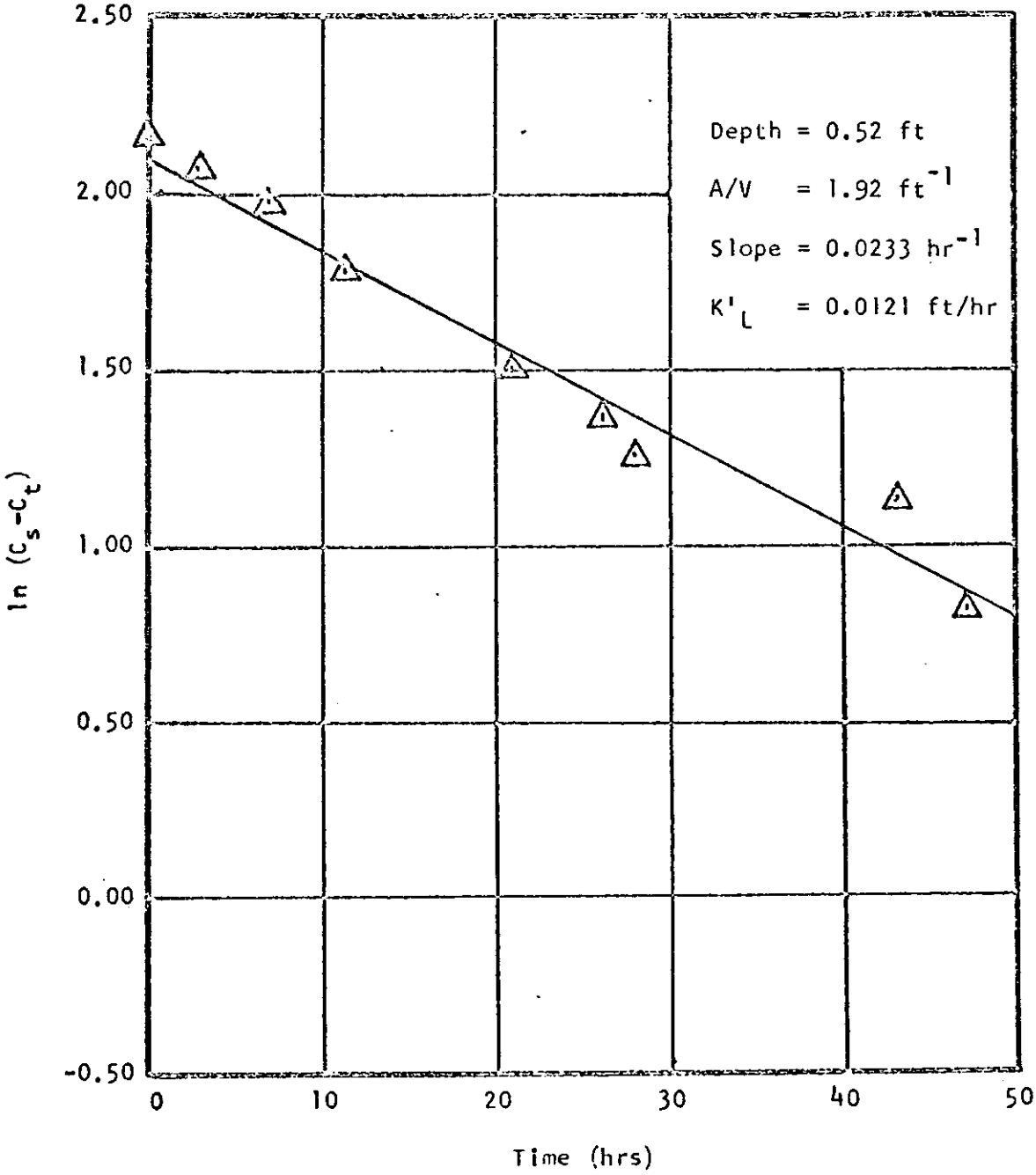


Fig. 30 OXYGEN TRANSFER COEFFICIENT AT 21°C USING BLENDED WATER WITH "AQUASAVE" - BY D.O. METER

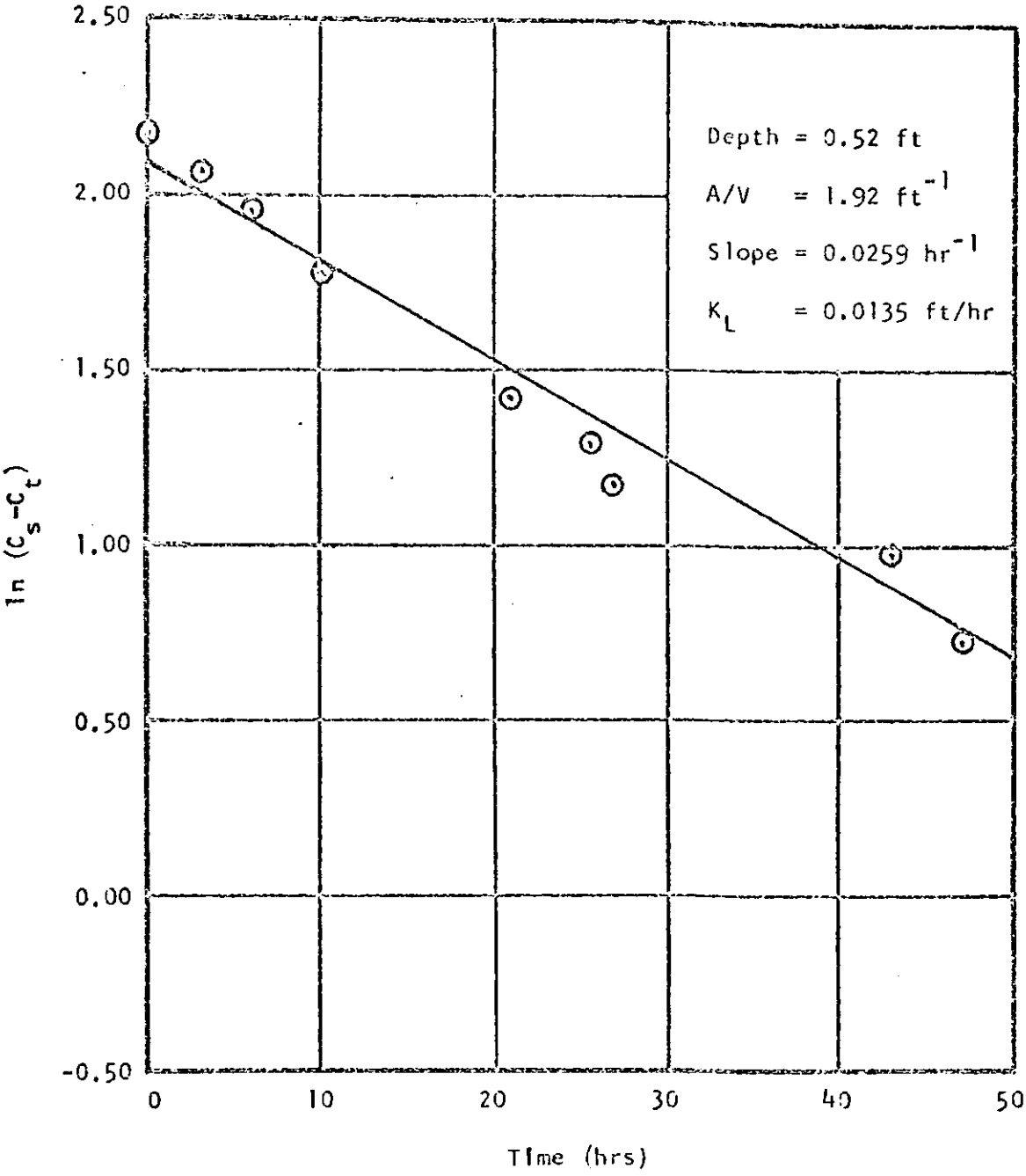


Fig. 31 OXYGEN TRANSFER COEFFICIENT AT 21°C USING BLENDED WATER WITHOUT "AQUASAVE" - BY D.O. METER

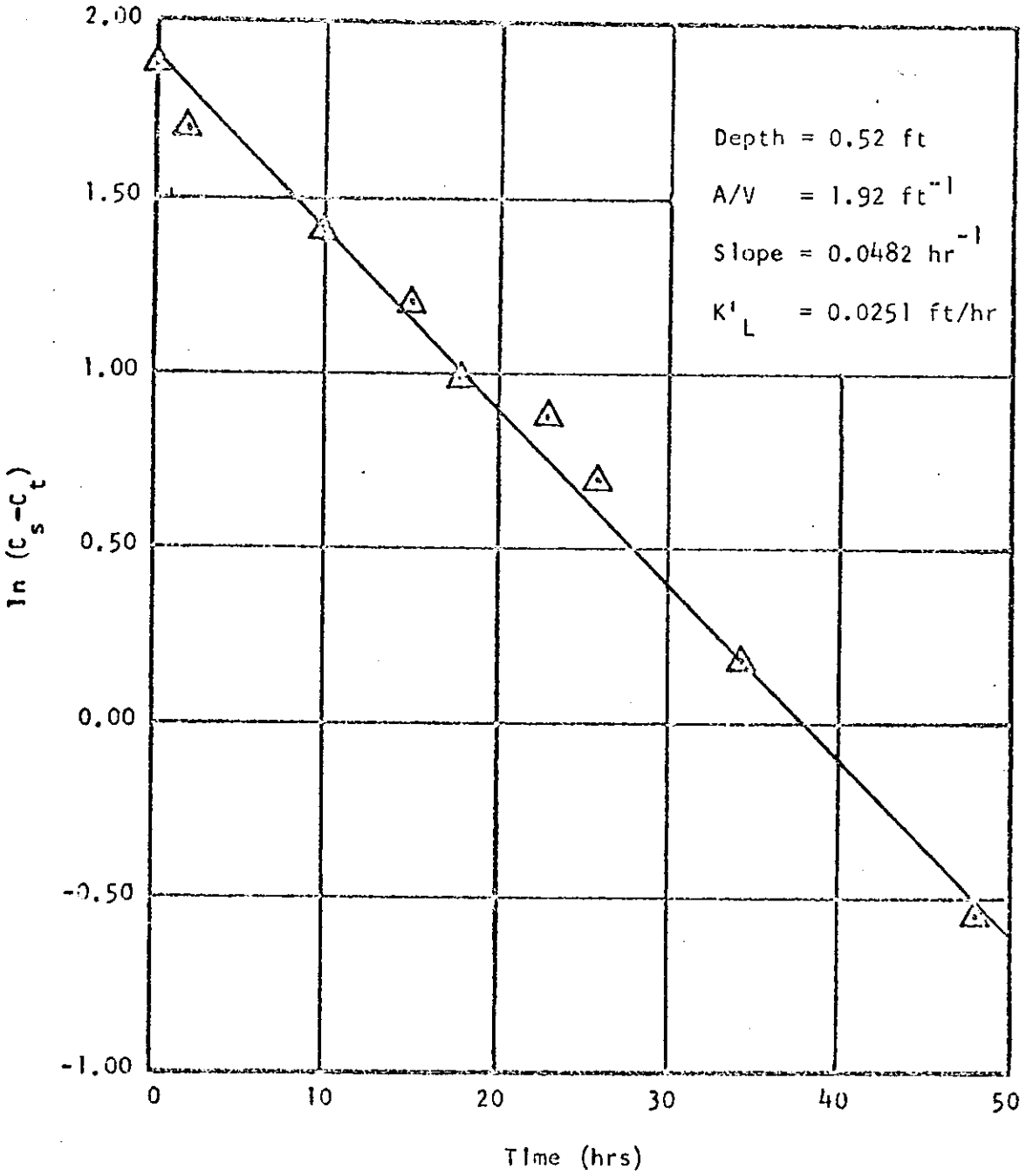


Fig. 32 OXYGEN TRANSFER COEFFICIENT AT 36°C USING BLENDED WATER WITH "AQUASAVE" - BY D.O. METER

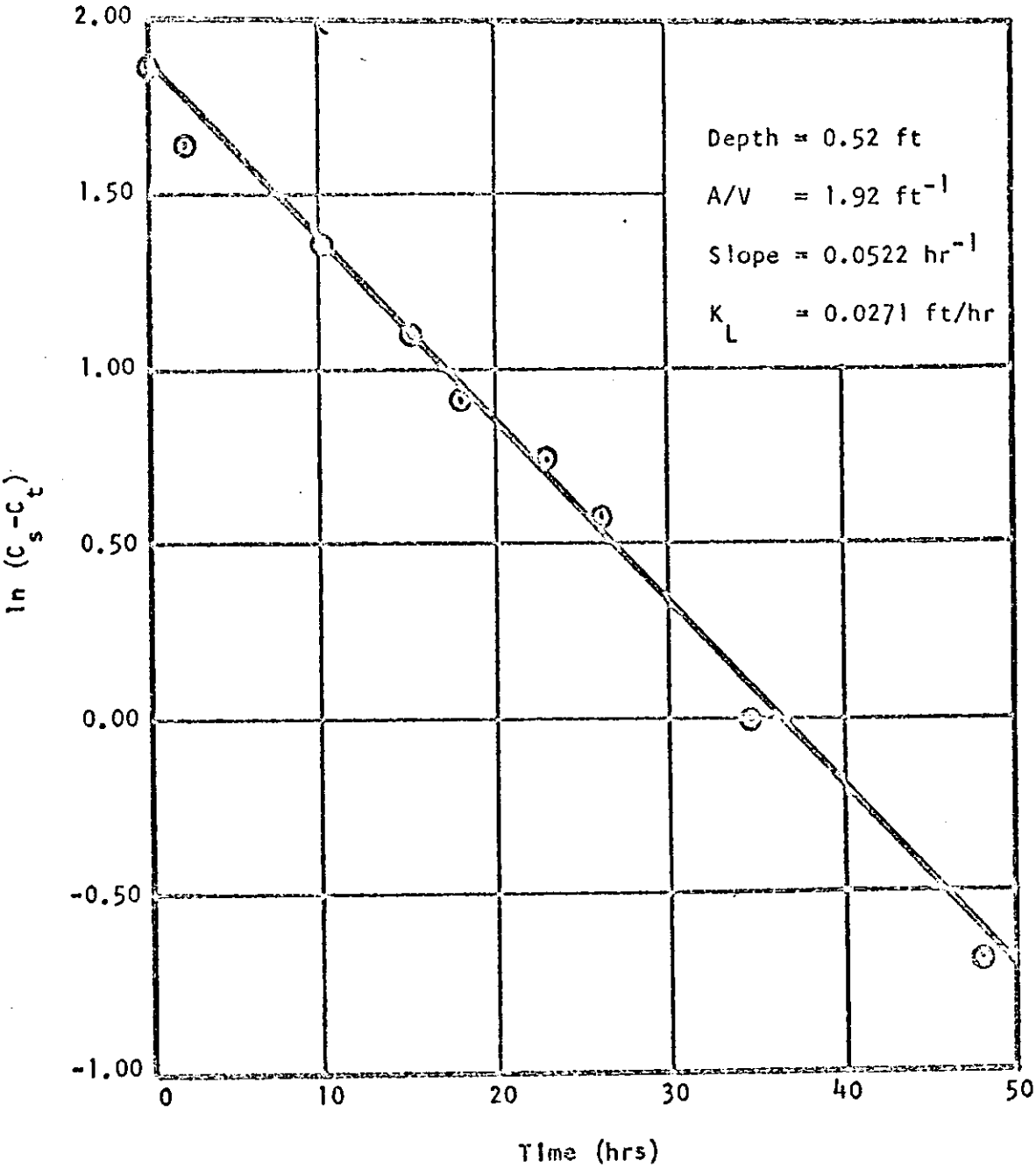


Fig. 33 OXYGEN TRANSFER COEFFICIENT AT 36°C USING BLENDED WATER WITHOUT "AQUASAVE" - BY D.O. METER